TRANSACTIONS

OF THE

ILLUMINATING ENGINEERING SOCIETY

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VOLUME I—No. 5
MAY 1936

32 VICTORIA STREET
LONDON SWI

NOTES ON RECENT MEETINGS AND EVENTS

General Meeting in London.

A general meeting was held in the Lecture Theatre of the Institution of Mechanical Engineers (Westminster, S.W.1) on Tuesday, April 7. The chair was taken by the President at 7 p.m.

The minutes of the last meeting having been taken as read, the names of applicants for membership were presented in the usual way.

The President then called upon the following authors to present their papers:—

Mr. R. C. Walker on "Some Applications of Modern Light Sensitive Cells."

Mr. L. H. McDermott on "Some Applications of the Photo-electric Cell to Problems Relating to Daylight Illuminations."

Mr. W. H. B. Hall on "The Rectifier Photo-electric Cell Applied to the Control of Gas Lighting."

An interesting discussion followed, in which the following took part:—Dr. J. W. T. Walsh, Lieut.-Colonel Kenelm Edgcumbe, Mr. W. Gilbert, Dr. S. English, Mr. Renshaw, Dr. J. Whitaker, Mr. J. S. Preston, Mr. C. H. Dobell, Mr. P. J. Waldram, Mr. F. C. Smith, and Mr. G. H. Wilson.

The President, in terminating the proceedings, proposed a cordial vote of thanks to the authors of papers, which was carried with acclamation.

Informal Meeting on March 31.

The second informal meeting of the session, devoted to "Questions and Answers" was held at St. Ermin's Hotel on March 31 and proved to be a very successful event. In the unavoidable absence of Mr. F. C. Smith, Mr. J. G. Clark presided. Amongst those who raised and endeavoured to answer queries were Mr. H Buckley, Mr. A. G. Brown, Mr. A. Cunnington, Mr. J. S. Dow, Mr. Howard Long, Mr. F. K. Sawyer, and Mr. G. H. Wilson, and the duration of the meeting had to be extended in order to allow time to deal with the great variety of topics brought forward.

Local Centres in Glasgow and Dublin.

Preliminary steps towards the formation of informal local centres in Glasgow and Dublin, similar to that already existing in the North Western Area in England, are now being undertaken.

Those interested should approach Mr. T. Catten (Lighting Service Bureau of Scotland, 29, St. Vincent-place, Glasgow) and Mr. J. Creagh (1, Ashbrook Villas, Ashbrook House, Sallymount-avenue, Ranelagh, Dublin).

APPLICATIONS FOR MEMBERSHIP

Elections Pending.

At the general meeting of the Society, held on April 7, the names of the following applicants for membership were presented:—

SUSTAINING MEMBERS:—

Edison Swan Electric Co., Ltd. ..... 155, Charing Cross Road, LONDON, W.C.2
(*Representative*:—Mr. A. Mansell.)

Straight-Lite Reflectors, Ltd. ..... 73, Canonbury Road, LONDON, N.1.
(*Representative*:—Mr. T. Bigland.)

CORPORATE MEMBERS:—

Dobell, C. H. ..... Radiovisor Parent, Ltd., 28, Little Russell Street, LONDON, W.C.1.

Richbell, P. ..... 40, Blenheim Park Road, SOUTH CROYDON

Wechsler, B. ..... 47, Farringdon Road, LONDON, E.C.1.

COUNTRY MEMBERS:—

Blackmore, J. P. ..... The Bombay Gas Company, Bombay, INDIA

Hoyle, H. E. ..... 92, Walkley Crescent Road, Walkley, SHEFFIELD.

Jones, R. ..... Mount Merrion Park, Blackrock, DUBLIN.

McGough, H. D. ..... 27, Calderwood Road, Griffith Avenue, DUBLIN.

O'Connell, G. T. ..... 14, Fownes Street, DUBLIN.

O'Connor, J. ..... 6, Richmond Row, PORTOBELLO.

Thornton, F. G. ..... Oakhurst, Avoca Road, Blackrock, DUBLIN.

Pleijel, G. Wilhelm... De Geergateb, 8.IV., STOCKHOLM.

ASSOCIATES:—

Buckingham, R. W. ... 3, Holborn Place, High Holborn, LONDON, W.C.1.

Fenwick, C. E. ..... Electricity Commission, Savoy Court, LONDON, W.C.

Elections Completed.

At this meeting the names of those announced on March 10, which were published in the last issue of the "Transactions" (Vol. 1, No. 4, p. 48, April, 1936), were read again, and these applicants were formally declared members of the Society.

Recommended Values of Illumination—*(ERRATA)*.

The attention of members is drawn to the following corrections in the "Recommended Values of Illumination," which recently appeared in the Transactions of the Illuminating Engineering Society (Volume I, No. 3, March, 1936, pages 42-44).

Page 43—

Public Buildings.
Library. Backs of Books ..... 2-4 ft.-candles

Coal Breaking.
Washing and Screening ..... 2-4 ft.-candles
Control Points and Picking Belt ..... 15-25 ft.-candles

Drawing Office. Main heading in thick type.

Page 44—

Tobacco Products. For "Stiffing" read "Stripping."

APPLICATIONS OF ULTRA-VIOLET LIGHT AND SOME ASPECTS OF FLUORESCENCE AND PHOSPHORESCENCE

By F. E. LAMPLOUGH, M.A. *(Member)*

(Presented at the Meeting on Tuesday, January 14th, 1936.)

Introduction.

In general the radiation emitted by a source of light is not confined to rays which render objects visible to the human eye, and which are therefore loosely spoken of as the "visible" rays, but extends into either or both of the regions outside the limits of the visible spectrum so as to include the "invisible" infra-red and ultra-violet rays.

The illuminating engineer in his work with ordinary light sources is not usually concerned directly with any infra-red and ultra-violet rays which may be associated with the visible rays, and most of the problems of illumination with which he has to deal can be considered without any knowledge as to what particular accompaniment of invisible radiation the visible rays may have. It is, however, becoming widely realised that these invisible rays are of very great importance from the point of view of the efficiency of luminous sources. All the older incandescent sources of light emit a large proportion of their energy as non-luminous infra-red rays, and apart from any value of the heating effect, such energy is wasted. Thus, with a tungsten lamp operating at the high colour temperature of 3,000°K only 9 per cent. of the radiation is in the visible spectrum. A similar waste of energy occurs in respect of the ultra-violet rays, but in the case of incandescent sources the energy of such rays is small. The ultra-violet rays have, however, other properties which make them of very great interest and importance.

Fluorescent Effects.

This is not the occasion to speak of the vital importance to all animal life of the ultra-violet rays of wave-lengths 2,900 to 3,200 Å.U. in natural light, but their power of producing luminous effects, known as fluorescence, under suitable circumstances is a fitting subject for the attention of the illuminating engineer. It is only necessary to consider the part played by fluorescent substances in modern photography, in the production of X-ray, visual and photographic pictures, in television, and in some gaseous discharge lamps to realise the enormous present and future importance of the subject.

When incident light is absorbed by a body one or more of three effects may be observed:—

(1) The absorbed energy is converted into heat and raises the temperature of the body.

(2) The body emits light of a different colour so long as it is exposed to the radiation.

(3) Energy is stored in the body which continues to emit light after exposure has ceased.

The second and third phenomena are spoken of as fluorescence and phosphorence respectively. When produced by visible light, fluorescent effects with solid substances are more or less modified or masked by reflection of part of the light, but when produced by exposure to invisible ultra-violet rays, the luminosity of the object is entirely due to fluorescence and the effect is much more striking and characteristic.

When invisible ultra-violet radiation is thus converted into visible light, from the point of view of the production of light, something is obtained for nothing, provided the fluorescent materials do not obstruct more visible light than they produce. This use of fluorescence in the economical production of light has already received attention in meetings of the Society, especially in the lecture by Dr. Pirani last summer on "The Production of Light."

Fluorescence is a very widespread phenomenon, and most substances exhibit it to some extent under suitable conditions. Its discovery, however, is of rather recent date, and its accurate description much more recent.

The luminous appearance of the tinctures of certain woods was noticed in 1570, and Grimaldi in 1665 observed, in a darkened room, the luminosity of the path of light through the liquid. Newton made some experiments, but with less than his usual care and insight, using incident light of different colours. Wünsch, in 1792, used the spectrum in his experiments. Herschel also gave attention to the subject, and Brewster, in 1833, experimented with other substances, particularly chlorophyll and fluorspar. All these investigators supposed that the emission of light was caused by the internal scattering of selected colours present in the incident light. The fluorescence observed by the earlier workers was bluish in colour and not excited by green to red rays, which would help to explain their failure to comprehend the phenomenon better, but one is at a loss to understand why Brewster failed to note that the blood-red fluorescence of chlorophyll could be produced by light which contained no red component

Stokes's Law.

It was not until the investigation of Stokes in 1852 that it was realised that the light emitted by the fluorescing material was different from that to which it was exposed. Stokes was led to conclude from his experiments that the colour of the emitted light was constant and independent of that of the exciting light and that the wave-length of the emitted light was always greater than that of the incident light. This latter generalisation is known as Stokes's Law.

Nichols and Merritt showed that Stokes's Law is not always literally correct, as the region of absorption of the exciting light may partially overlap the spectrum band of the emitted light. In such cases when fluorescence is produced by the longest wave-

length possible, a portion of the emitted light has wave-lengths shorter than that of the exciting radiation.

It is not always the case that the fluorescence colour is independent of the colour of the exciting radiation, as a given substance may have more than one distinct fluorescence, and as the wave-length of the incident light is increased, the fluorescence of shorter wave-length will disappear at a particular point. Thus chlorophyll exhibits a deep red and a weaker greenish fluorescence.

Resonance Radiation.

Certain phenomena in the vapour state which have an important bearing on theory may be mentioned briefly. R. W. Wood showed that a tube filled only with (monatomic) sodium vapour at the low vapour pressure at 140°C. glowed with yellow light when illuminated with the same kind of light. This emission is spoken of as "resonance radiation," and strictly does not come within our definition of fluorescence unless regarded as a limiting case. This occurs as the result of energy changes which take place within the atom, when electrons return to an inner orbit from which they have been displaced by the incident radiation.

In the case of monatomic mercury vapour the resonance radiation is deep in the ultra-violet (2536 Å.U.), and observations must therefore be made, using a quartz tube and photography of the "glow," by means of a camera with a quartz lens, using incident radiation of the same wave-length. In this case no heating is required, and although the vapour pressure is so minute, the resonance radiation may be detected as low as —50°C., i.e., below the freezing point of mercury. If the tube is heated, the absorption of the radiation of resonance wave-length is so strong that the rays can no longer penetrate the whole bulb, and the glow only takes place close to the wall of the bulb facing the incident rays. Under other conditions of irradiation these vapours exhibit true fluorescence due to the return of electrons from higher orbits, but this phenomenon is at present of less practical than theoretical interest.

The Efficiency of Fluorescence.

Under suitable conditions at very low pressure, a mercury gaseous discharge lamp gives only the resonance radiation line in the ultra violet, and if this radiation is allowed to fall on suitable fluorescent material of high efficiency to convert it into radiation of high visual intensity, a lamp of good efficiency should be obtainable. In this way fluorescence may come to our aid in our efforts to get a step nearer to the maximum possible efficiency of a light source.

The efficiency factor of a fluorescent material is the ratio of the energy of the emitted light to that of the incident light which is absorbed by the material. In the case of resonance radiation all absorbed energy is emitted again without loss, if no foreign gas is present. The efficiency cannot in any case exceed the ratio of the wave-length of the exciting radiation to that of the emitted light. Fluorescein in very dilute solutions shows efficiencies up to 75 per cent., and some other organic compounds and some inorganic salts, especially crystalline platinocyanides, uranyl salts, and certain sulphides are very efficient.

Influence on Colour of Sources.

The use of fluorescence to vary the colour of a source of light has already received attention at more than one meeting of the Society. The use of coloured glass tubes with mercury and neon discharge lamps is, however, in most cases a more efficient method of obtaining coloured effects. In the case of the mercury vapour lamp for use in factories, reflectors coated with a compound, which gives a red fluorescence, have been used to correct to some extent the unpleasant green colour of the light from the lamp.

Apparatus for Analytical Work.

A widespread application of fluorescence is to detection, discrimination, and analysis. This work is carried out by visual and photographic methods. As the presence of any considerable proportion of visible light in the incident radiation will mask weak fluorescent effects, and it is desirable to examine fluorescent effects extending to the violet end of the spectrum, ultra-violet light must be used for excitation, and must be as free as possible from visible rays.

It would, of course, be possible to employ the X-rays which are very deep in the ultra-violet and thereby obtain important fluorescent effects (such as are used in X-ray fluorescent screens and in X-ray plates, with which Dr. Levy will be dealing, will be mentioned later), but there are many disadvantages associated with the use of X-rays for this purpose, and most of the enormous amount of work which had already been recorded has been

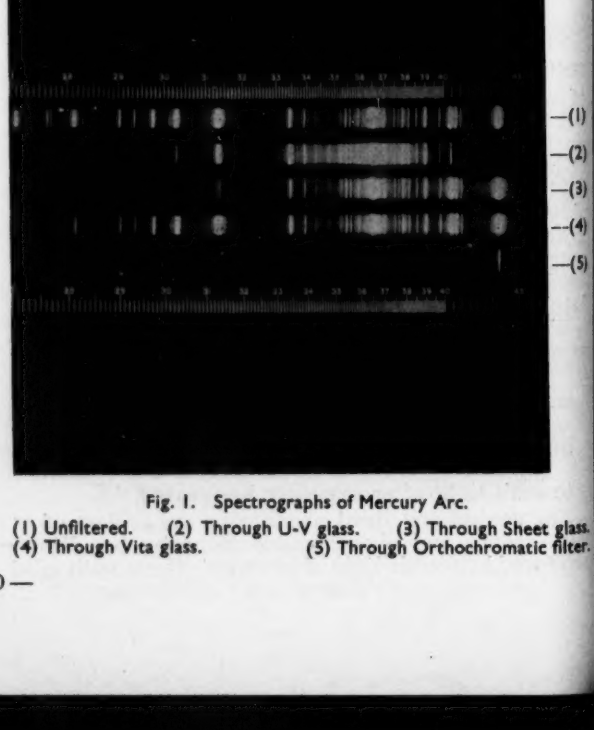

Fig. 1. Spectrographs of Mercury Arc.
(1) Unfiltered. (2) Through U-V glass. (3) Through Sheet glass. (4) Through Vita glass. (5) Through Orthochromatic filter.

carried out with the near ultra-violet rays of wave-length 3,000 to 4,000 Å.U. These rays are conveniently produced by filtering the radiation from a good source of ultra-violet light through a screen which will remove as much as possible of the visible light. Many filters have been employed for this purpose; some workers have used dye solutions or dyed gelatine, and the wide choice of these available enables particular regions of the spectrum to be isolated for special purposes. Such filters are subject to disadvantages including sensitivity to changes of temperature and, in many cases, to fading in the intense ultra-violet light.

For all ordinary practical work it is more satisfactory and quite sufficient to use a filter made of a glass containing a high proportion of nickel, as first suggested by Wood. This black "ultra-violet glass" is made in this country and has a maximum transmission near 3,600 Å.U., thus efficiently transmitting the strongest radiation (3650/63 Å.U.) of the high pressure mercury lamp. It has, however, the drawback of transmitting a little extreme violet and extreme red. Alternatively a convenient filter can be made by silvering two thin pieces of "Vita" glass and binding together with the silvered sides facing. The two films prevent leakage through pinholes which may be present. Transmission is a maximum at 3,270 Å.U., which is not ideal for the mercury lamp, and there is difficulty in adjusting the silvering so as to give just the transparency required, but there is no transmission of red light. For most purposes the quartz mercury vapour lamp with U.V. glass has been adopted as the source of light, thus facilitating the comparison of results. The tungsten arc is an excellent, simple, steady and less costly source of ultra-violet rays, but d.c. has to be provided for its operation. The mercury lamp has the advantage of giving little red light, so that the transparency of U.V. glass in the extreme red has negligible effect. Visual examination of the fluorescent effects enables the observer to distinguish materials not only by the brightness of the fluorescence but also by its colour which varies both as regards hue and purity. It is often, however, essential to obtain photographic records. To obtain the fluorescent picture, the subject is illuminated by the ultra-violet lamp and is photographed by a camera equipped with a suitable filter to absorb all ultra-violet scattered or reflected by the subject. The absorption of this filter should be chosen according to the particular region of ultra-violet light used for illuminating the subject, and panchromatic plates are usually employed.

If only occasional examinations of no great delicacy are to be made, it may be possible to dispense with the arc or mercury vapour lamp. Sunlight passed through black U.V. glass will enable bright fluorescence to be observed, but tests which the writer has carried out with burning magnesium ribbon show that this is superior to sunlight, but has obvious inconveniences. For many tests, suitably controlled, even a tungsten gas-filled lamp, preferably overrun, may be used with U.V. glass. In emergency, two or three thicknesses of pot. cobalt blue glass will absorb the most luminous parts of the spectrum and transmit the near ultra-violet, and enable a number of phenomena of fluorescence to be observed.

Some Applications in Practice

A consideration of some of the effects which are obtainable with these methods of examination shows that the amount of material is so large that only a slight indication can be given of the directions in which fluorescence tests have proved of value. The fluorescent effects given by materials endow us, as it were, with a completely new, independent colour sense, and workers in every field have been quick to make use of it.

As the fluorescence colours bear no close relation to the natural colours of substances it very commonly happens that colourless materials or those of identical natural colour can be distinguished with the greatest ease by their fluorescence, and the application of the test does not use up any of the materials, or leave its trace behind, and is made in a few seconds.

The method of examination is frequently of great value in detecting small amounts of impurities, whilst the work of museum experts, collectors, and criminologists is immensely assisted by its aid.

One of the earliest applications to museum work was the use made by Kögel in 1914 of ultra-violet light for deciphering palimpsests, i.e., ancient parchments from which the original writing had been erased by sand or pumice to make it available for a new document. Fig. 2 shows two remarkable photographs by this worker of a palimpsest taken with visible and ultra-violet light respectively.

X-rays and the examination in ultra-violet light are powerful aids in the examination of pictures for the detection of alterations, retouching, and overpainting, and for the determination of age. Ultra-violet light at once shows the difference between old and freshly cut marble and plaster of paris used for repairs. In the same way newly cut ivory or bone can be distinguished from old, whatever efforts have been made to age it, such as pickling in manure, tobacco juice, or giving to a turkey to swallow! Incidentally, it may be mentioned that natural teeth, like ivory and bone, fluoresce a brilliant white, whilst artificial teeth are most strikingly obvious by their darkness, being usually black or deep chocolate.

Repairs to pottery, glass, and woodwork are at once evident, whilst philately furnishes very many examples of the use of the ultra-violet lamp in the detection of fraudulent imitation of the paper or printing ink, and even the gum of a stamp may give valuable evidence of genuineness.

It will readily be realised that the lamp is a terror to the criminal, whether it is used to detect and recognise incriminating stains or dust on clothing, erasures in forgeries, messages from prisoners in invisible "inks" (saliva, urine, fruit juice, milk, etc.), spurious banknotes, additions to typed documents, bloodstains, etc. Fingerprints which would not show

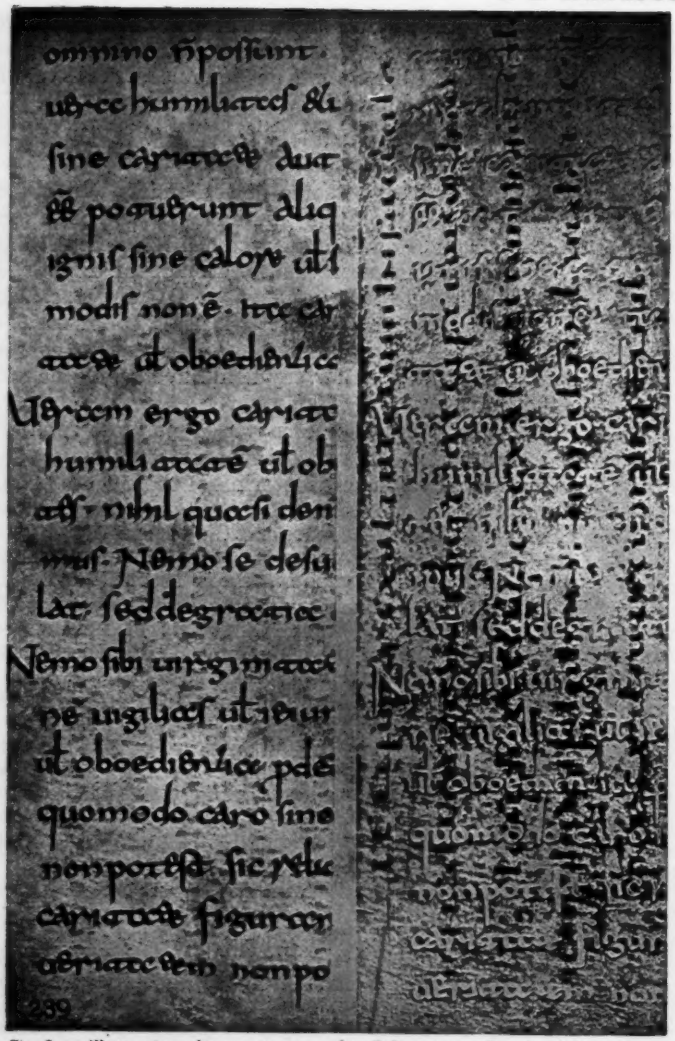

Fig. 2. Illustrating the appearance of a Palimpsest. On the *left* is seen a photograph by ordinary light, and on the *right* a luminogram showing the older writing underneath.

This picture, due to Professor Kögel, and kindly furnished by Hanovia Ltd., appears in the book by Mr. J. A. Radley and Dr. Julius Grant entitled "Fluorescence Analysis in Ultra-Violet Light."

up well on some objects can be made to stand out brilliantly by dusting with a highly fluorescent powder.

A vast amount of work has been done on the application of the lamp to the recognition of inorganic and organic substances, drugs, oils, minerals, rubber, papers, paints, and varnishes. In the medical field, one of the most striking fluorescent effects is given by the microspores of ringworm, which glow with a green light so that, in the absence of ointment, ringworm can be readily detected, and many large schools include a lamp in their equipment. The light can also be used in the recognition of bacteria after suitable staining, and in other directions.

The examination of foodstuffs provides another field of usefulness for dark ultra-violet light. Thus, various kinds of flour may be distinguished, and a good idea obtained as to the gluten content in wheat flour.

Some preservatives, notably salicylates, show their presence in a very minute amount.

In the case of butter, 5 per cent. of cocoa fat or 20 to 25 per cent. of margarine may be detected. The ripening of cheese is very evident from the bright light green fluorescence of living fungi. The fluorescence of egg albumen also increases with age, and the shell is said to change gradually in fluoresence after ten days from red through red-violet to blue. The list might be extended indefinitely, and includes also the recognition of meats, vegetable products, fruit pulp and juices, wines, vinegar.

An important use of fluorescence in the laboratory is its application to the titration of liquids having colours which would mask the colour changes of indicators. One of the fluorescent indicators most favoured is umbelliferone, which becomes non-fluorescent in acid solution.

In the examination of textiles and paper, fluorescence may play an important part, discriminating animal and vegetable fibres, natural, and artificial silk, and detecting mildew, traces of oil stains, etc. In the case of paper, elaborate work has been carried out by Judd Lewis, by placing the sample in the dark slide of a quartz spectograph and projecting upon it the ultra-violet spectrum. The fluorescent picture so obtained is viewed or photographed, and in the latter case, ultra-violet fluorescence, invisible to the eye, is also recorded.

Fluorescence may even play a part in the unlikely field of palæontology and yields striking pictures of fossils which are indistinct in visible light.

The strong fluorescence of mineral oil has an application in spectrum photography of the far ultra-violet. Where the wave lengths are so short that the rays will not penetrate a minute film of gelatine on the silver salts, a trace of mineral oil rubbed over the plate will fluoresce in the rays and give rays which easily penetrate gelatine, and so record the spectrum.

Display and Advertisement.

Some use has been made of fluorescence for display and advertisement. Fluorescent uranium glass has long been used for ornamental objects and vessels. Posters have been made from fluorescent materials, which are frequently exhibited in the windows of chemists' shops. In stage and film work effects can be obtained by fluorescence which are striking and unique—ghosts miraculously appear and disappear, and costumes which glow in the darkness add effect to a dance. Extensive use was made of fluorescence in the film production of H. G. Wells's "Invisible Man." If the skin of the actor is made

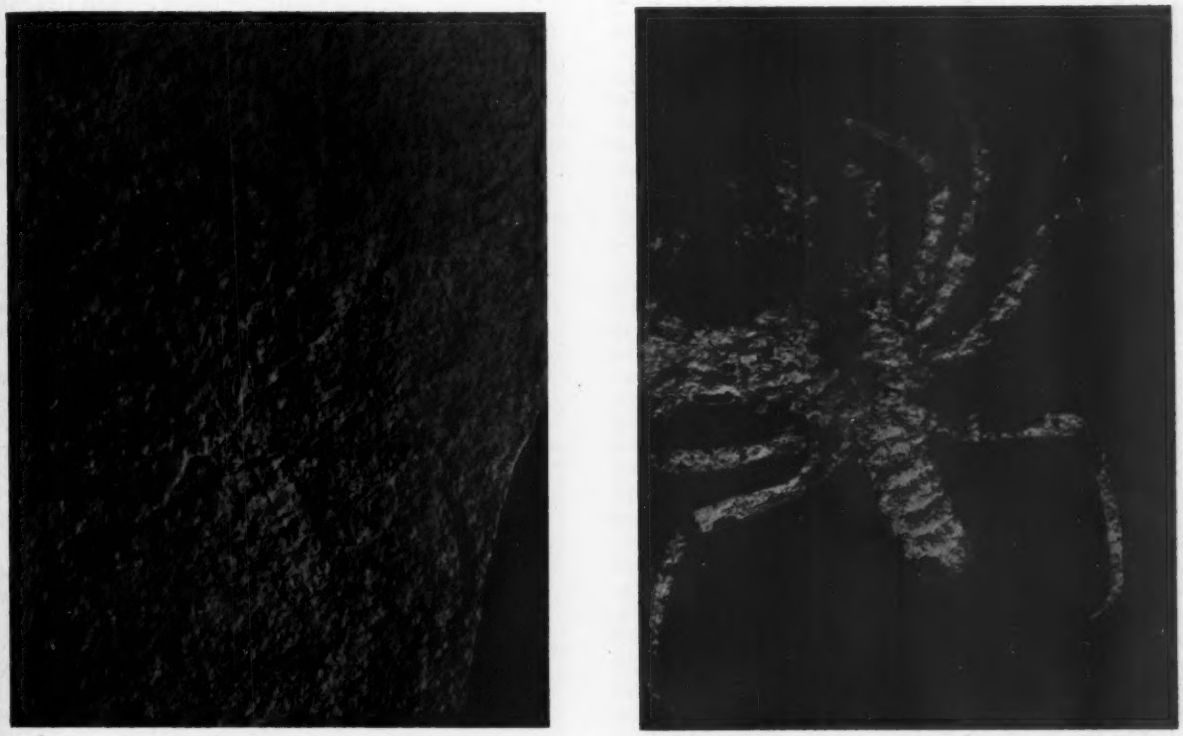

Fig. 3. Showing the Appearance of a Fossil. On the *left* is seen a Photograph by Ordinary Light, and on the *right* a Luminogram in which the fossil is clearly revealed.

This picture, due to Professor Miethe and kindly furnished by Hanovia, Ltd., appears in the book by Mr. J. A. Radley and Dr. Julius Grant entitled "Fluorescence Analysis in Ultra-Violet Light."

non-fluorescent, and his suit is strongly fluorescent then in dark ultra-violet light the suit can walk about amazingly without visible means of support.

Phosphorescence.

Phosphorescence in its widest sense covers all phenomena in which at any time there is emission of light from a substance without simultaneous excitation by heat, light, or electricity.

There are four chief divisions of this phenomenon:

(1) "Bioluminescence," or the emission of light from organisms, firefly, glowworm, fishes, plants, jellyfish, bacteria, fungi, and from animals in pathological conditions (luminescent diseases).

(2) The glow of slowly oxidising phosphorus, decaying fish, meat, wood.

(3) "Fluorescence of long duration" which continues for a brief moment after extinction of the exciting radiation, e.g., platinocyanides, uranium glass.

(4) The after-glow of certain crystalline substances, especially sulphides, which contain minute traces of impurities, and store energy and remain luminous after the exciting rays have been extinguished.

Of these classes (1) presents points of interest to the illuminating engineer, and (4) is of practical importance.

The first phosphorescent substance of class (4) was discovered in 1602 by a cobbler of Bologna, and was therefore called Bolognian phosphorus. This was obtained by heating mineral barium sulphate in a furnace, thus producing a certain amount of barium sulphide. In 1652 Zecchi found that the emitted light for a given sample was constant in colour whatever the colour of the exciting light, and the emitted light had therefore not been stored up unchanged.

Great difficulty was, however, experienced in repeating results. This has, in recent years, been found to be due to the fact that the luminosity is caused by varying minute amounts of different impurities. In some cases as little impurity as one in one million produces phosphorescence, and the maximum effect may be produced with as small a proportion as one in 10,000. Cadmium sulphate crystals, when purified with the utmost care, give no phosphorescence, but 0.1 per cent. of zinc sulphate gives intense blue, whilst with magnesium it emits green light after activation.

Exposure to the temperature of liquid air for the time suppresses the emission, whilst infra-red or red radiation extinguishes the glow, usually after a

rapid flare up, which may differ somewhat in colour from the normal emission. This extinction can be used in mapping the infra-red spectrum.

Becquerel, in 1872, investigated phosphorescence of momentary duration by a mechanical device for alternately irradiating and viewing in rapid succession, the substance under test, and ascertained that very brief phosphorescence, e.g., 0.01 second was common and similar in character to the fluorescence of the material, and was also subject to some control. He therefore named this "fluorescence of long duration."

It would therefore appear that there is no sharp distinction between fluorescence and phosphorescence. The fluorescence of solutions and gases appears, however, to be due to changes within the atom or molecule, whilst various electrical and physical tests of activated crystals appear to indicate that the latter is due to the passage of electrons between the molecules in a crystal lattice which is deformed by the impurities present, the slow return of the captured electrons producing the light emission, whilst the temperature vibrations of the molecules play a part in the process.

Bioluminescence.

In conclusion a brief reference may be made to "bioluminescence," which exhibits great variety. Bacteria and fungi shine day and night independently of stimulation, other organisms only when stimulated. Some fishes have the luminous part dangled in front on a sort of antenna, a signal to attract prey, but more usually the purpose of the luminosity is to bring the sexes together. Air and water are necessary for the emission, but dried cells become luminous on moistening.

The light from the firefly occupies a band near the middle of the visible spectrum, and as it is not accompanied by infra-red and ultra-violet rays the efficiency of production is very high, approaching the theoretical maximum. The overall efficiency in terms of the input of food energy is another matter, but probably the firefly deserves the halo conferred on it when comparison is made with the efficiency of a power station in producing light from a given consumption of coal.

It has been found that the light-giving body consists of an oxidisable material plus an enzyme or catalyst, which is destroyed on boiling. The oxidisable material can be purified, and after oxidation can be reduced again, and it is conceivable that the synthesis of this may some day be practicable, and a method developed for the production of light by its oxidation.

It is desired to acknowledge the courtesy of Messrs. Chapman and Hall, who granted permission for the reproduction of the two illustrations from "Fluorescence in Ultra-Violet Light," mentioned above, and also the assistance of Hanovia, Ltd., in furnishing these photographs and for the display of exhibits.

Acknowledgment should also be made of the valuable help of the following, whose exhibits contributed greatly to the interest of the address and the subsequent discussion:—

The British Thomson-Houston Company, Ltd., Messrs. Chance Brothers and Co., Ltd., Claude Neon General Neon Lights, Ltd., The General Electric Company, Ltd., Messrs. Kelvin, Bottomley and Baird, Ltd., Dr. Leonard Levy, The Strand Electric and Engineering Company, Ltd., The Thermal Syndicate, Ltd., and the Wool Industries Research Association.

DISCUSSION

Dr. LEONARD LEVY remarked that a great deal of the work which had been done was not really concerned with fluorescence itself but rather with the information regarding the qualities of various substances deduced from the nature of the fluorescence exhibited. He, on the other hand, proposed to say something about fluorescence as such. The first main application of fluorescence was in X-ray work in which a fluorescent screen was used to convert the invisible X-rays into visible fluorescence to enable visual examinations of a patient to be made. In taking X-radiographs the exposure was very greatly reduced by means of intensifying screens which served to convert the X-rays—which did not have a very great effect upon a photographic emulsion—into visible radiations which had far more effect upon the emulsion. Other important applications of fluorescence were in connection with self-luminous compounds and television. Fluorescence was a very general phenomenon and easily produced so far as ultra-violet light was concerned, but in the case of X-rays, radioactive substances and television; the matter was very different In these cases the maximum fluorescent power possible was required and its production was a matter of the very greatest difficulty. Certain substances would produce more intense fluorescent effects than others, the most important being the different varieties of zinc sulphide and zinc cadmium sulphides. These materials had to be prepared under conditions which were similar to those which bacteriological workers had to apply, and the most minute traces of compounds of certain metals entirely spoiled the results. There were also certain other desiderata which had to be considered. In the case of X-ray screens for medical work, it was essential they should not display any phosphorescence whatsoever, otherwise the outlines would be blurred and diagnosis would be rendered difficult or impossible. It was also necessary that the time of exposure should be reduced as much as possible. Until comparatively recently barium platinocyanide and cadmium tungstate—latterly only cadmium tungstate—had been used for fluoroscopic screens. Zinc and zinc cadmium sulphides displayed far more intense luminescent effects, but the fluorescence was always accompanied by phosphorescence. Extended research had, however, resulted in the production of a type of zinc cadmium sulphide which gave the necessary

fluorescence without phosphorescence, and in this way the illumination now obtainable was six or seven times what it used to be, thus enabling the exposure to be reduced considerably—an advantage not only to the patient, but also to the radiologist. In addition the life of the X-ray tube was much increased. In analytical work perfection of fluorescence was not important so long as the information required could be obtained.

Another important application of fluorescence was the production of self-luminous paints which consist of a fluorescent body mixed with a very small amount of radioactive material. At one time radium salts were used almost exclusively, but now mesothorium had largely supplanted the latter. The substance found to be by far the best for making self-luminous paints was zinc sulphide prepared in a special way in order to obtain the maximum fluorescence as well as phosphorescence. It was necessary that a small amount of copper should be present as a phosphorogen. Zinc sulphide mixed with a small amount of radioactive material—about 0.4 mg. per gram—did not maintain its fluorescence at a maximum for more than seventeen days, after this period the luminosity gradually diminished in intensity if radium was employed as the radioactive material. When mesothorium was used, however, the illumination remained constant for between two and three years after which it fell off gradually. At the present time it was possible to get the same illumination with half the amount of radioactive material which had to be used ten years ago. This obviously represented a considerable saving having regard to the fact that the luminous compound used for Government instruments, for example, was worth about £1 per gram.

Another application of fluorescence, as fluorescence, which would be of great value in the future was in the screens for cathode-ray tubes. This, indeed, was a present application, but it would become much more important with the development of television, because in that case the picture was simply represented by the difference of the illumination of the fluorescent screen which was caused by the bombardment of the cathode rays. In this case it was preferable that the colour of the fluorescence should be white in order to get a black and white picture.

During his remarks, Dr. Levy demonstrated the points he made, and concluded by showing some examples of zinc cadmium sulphides to indicate the effects which can be produced from the luminescence point of view.

Mr. F. P. BENTHAM dealt with the application of fluorescence to the theatre, and followed with some interesting demonstrations.

He explained that for this purpose it was necessary that fluorescent paint should be made up on a commercial basis, as very large quantities were necessary for use in theatres. For instance, some of the scenes at the London Coliseum had been treated in this way.

He pointed out that by using a special "dope," as he preferred to call it, a very realistic representation of the Indian rope trick had been given on the stage. In that case the whole scene was treated with various fluorescent paints and floodlit with ultra-violet light from mercury vapour lamps, with ultra-violet screens, situated in the footlights. Thus, any normal untreated person on the stage was invisible, while the scene remained visible. By these means, Mr. Lupino Lane came on to the stage into a pool of visible light thrown by an ordinary spotlight, started climbing the rope, and when clear of the spotlight rays, vanished completely.

Mr. Bentham added that fluorescent make-up was sometimes used for the Witches in "Macbeth" and similar situations. Such make-up, which was known as "Invisible Green," fluoresced a bright blue-green. but was completely invisible under white light.

Mr. C. H. WRIGHT remarked that Dr. Lamplough had done well to give a warning in respect to the use of a filter when making photographs of fluorescent effects; mistakes and misinterpretations were likely if this precaution was omitted. In regard to the use of ultra-violet radiation in criminology, an excellent example occurred in Glasgow. An aeroplane part, constructed of wood, canvas covered, and varnished, had been maliciously damaged. Signs of fingerprints were found, barely visible, and which would not react to the usual treatments, but a photograph taken under filtered ultra-violet radiation provided excellent prints, with detail sufficient to lead to the tracing of the culprit.

Mr. Wright explained that the firm with which he was associated had made a portable U.V. fluorescent hand lamp, for a well-known expert, for the examination of oil paintings in situ, which had proved of great value in detecting alterations, additions, and frauds.

He had on exhibition a convenient form of fluorescence testing cabinet, employing a quartz mercury lamp, and would be glad to show a number of interesting examples of fluorescence testing after the meeting. Meanwhile, he showed the fluorescence of a number of samples of rocks bearing veins of willemite (an ore of zinc)—those present would note the bright yellow fluorescence of this ore against the rest of the rock and would gather the relative value of the rock samples as sources of the ore.

In examining the human body for bacteria by their fluorescences, the filtered beam of U.V. radiation had proved of much value, especially in reference to the affections of the eye. Other human secretions might be recognised by their fluorescences, and this was used in criminal investigations. Arsenic stains involving extremely low concentrations could be seen by means of the fluorescences exhibited where they were not readily visible in ordinary light.

It would be of interest to refer to another important application of ultra-violet light, namely, the destruction of the bacterial content of water, such as that of swimming pools.

While the usual treatment of the pool water by calcium hypochlorite was effective in killing bacteria if sufficient free chlorine was present, the addition of more than 0.5 parts per million might have unpleasant effects on some bathers—affecting

the eyes, nose, and throat. Higher amounts of chlorine might cause the presence of free chlorine in the air of the bath with unpleasant effects on the spectators.

Accordingly, in some baths purification was successfully carried out by ultra-violet radiation. The water thus treated was unchanged in colour, "sparkle," etc. The production of ozone in the neighbourhood of a quartz mercury lamp was also taken advantage of in a well-known form of apparatus—air being drawn through the housing of the quartz burner and injected with the ozone into the bath.

The quartz lamp was housed in a quartz cylinder around which the bath water is circulated, the whole being mounted in a gunmetal casing with inlet and outlet flanges. Some germicidal tests, carried out by a bacteriologist, were quoted to show the short exposure necessary. Using an "atmospheric" quartz lamp and irradiating a four-inch depth stream of filtered sea-water collected at Greenock, an exposure time of 0.5 sec. reduced the bacteria from 81 to 2 per c.c., while exposure of 1.0 sec. was sufficient to sterilise this water effectively. Further trials with filtered sea-water heavily contaminated artificially with bacillus coli had led to similar conclusions.

Dr. H. J. PLENDERLEITH (British Museum), commenting on the many uses of the ultra-violet lamp in museum work, said that in a large archeological museum two distinct types of equipment were required; the first was for the general public and the second and more specialised apparatus for research purposes and photography. Specimens requiring investigation were often of such a size that two lamps had to be used at the same time; these were mounted at a convenient angle so that the observer or camera stationed between the lamps faced the object which appeared from this position to be in a uniform field of ultra-violet rays. Efficiency depended to a large extent on the nearness of the lamps to the object under examination, and thus the design of the housings was of primary importance. The lamp housings should be small and capable of infinite adjustment, and the filter screens should be comparatively large and as near to the source of illumination as considerations of temperature would allow. There was another form of lamp which he did not see exhibited, but which he felt was bound to come to the front in the future, and that was the small portable very efficient light-weight lamp which could be plugged into a normal lighting circuit when required. He had seen on the previous Friday what could be regarded as the prototype of this lamp from the Huntingdon library, San Marino, California. Superficially the instrument was rather like a reading glass, the current being supplied by a wire running through the handle, only the place of the lens was taken by a ring-shaped mercury vapour lamp which was opaque on one side. Observations were made through the centre of this ring, and a small area of a manuscript, for example, could be intensely illuminated from a distance of about one centimetre. A seeming disadvantage of this particular lamp was that it ran at 2,000 volts, but this would doubtless be overcome, and he felt that such an instrument would be a considerable advance for certain kinds of work on what they had been using in the past.

The problems which came before the authorities of the British Museum Research Laboratory were mainly problems of identification and interpretation or assessing the authenticity of various exhibits such as manuscripts, drawings, and ancient objects of applied art, and ultra-violet light had proved exceedingly valuable in many aspects of this work. The lamp was frequently useful in disclosing old repairs or repaints and in affording information as to the antiquity of patina and incrustations on bronzes. Counterfeit inscriptions and ornament had been brought to light by its means when other methods failed. The skill and ingenuity employed in the reconstruction of damaged or broken works of art or in making pottery up to simulate valuable antique types was often such as to deceive the connoisseur, and it was only by the use of ultra-violet light that the degree of falsification could be determined.

There was a great future for this type of investigation in museums; the complexity of exhibits rendered the attainment of positive results fairly certain and a greater facility of interpretation would doubtless come with specialisation and accumulated experience.

Mr. W. J. SCOTT said that the lecturer had very clearly shown the vast possibilities that arise out of the conversion of U.V. electric discharge lamp radiation into visible radiation by means of luminescent substances. This was a phase of the subject which particularly interested him and the firm with which he was associated.

Although it had been realised for many years that the use of "cold" light sources would come some time, it was only in the last few years, after the development of suitable cathodes and glasses, that the electric discharge lamp had come into prominence in forms readily amenable for use with luminiscent materials, and that the necessary technique for the manufacture and application of these powders had been developed.

In practice the methods by which the powders were used with different light sources might be classified in two main groups. Firstly, those which were incorporated in the discharge tube and were in contact with and excited by the discharge—for example, the low pressure mercury electric discharge tube which operated at fairly low temperatures and might be coated internally with zinc silicate giving an intense green colour, or with other powders giving other colours. Secondly, those which were placed on the outside of the tube or on surfaces illuminated by its radiation. An example of this was the high pressure mercury or mercury and cadmium vapour discharge lamp, in which a large area cool running surrounding fitting was coated with a red fluorescing powder which could increase the percentage of red

light from the lamp without very much reduction of overall efficiency, and a colour which gave very pleasant colour rendering indeed.

The 70 watt E.H.P. quartz mercury vapour lamp which had a spectrum richer in red than the ordinary high pressure mercury lamp could also be used with advantage in this manner and with a considerably higher luminous efficiency.

The efficiency of luminous materials varied considerably with temperature, and usually fell off very rapidly at temperatures much above 100°C. Hence, there was a definite minimum efficient size for the coated lamp according to its wattage, which was determined by the temperature efficiency of the material. In general it was usual with high wattage sources to operate at a temperature slightly in excess of the maximum efficiency point in order to get a more compact light source, in much the same way as in magnetic circuit design the flux density in the iron was usually in excess of that at the point of maximum permeability.

Mr. H. G. JENKINS demonstrated a number of cold cathode tubes of the type used for advertising and decorative lighting. These were coated internally with various luminescent powders. Attention was drawn to the number of new colours and the enhanced luminous output which these powders made possible.

Some of the tubes shown had been in use commercially for about two years and were characterised by the fact that mercury was used in the filling. Some of the very latest tubes were shown in which the powders were excited by pure neon. These gave rise to yellow, pink and pink-white colours, of which the latter was still in the experimental stage. It was suggested that these new colours would appeal to all who had become satiated with the familiar red and green tubes, so extensively used for advertising.

It was pointed out that an important result of this development work was the increasing use of high voltage tubes for general illumination purposes.

Mr. J. S. Dow explained that Mr. F. H. Vallency, the President of the London Stamp Club, had hoped to be present in order to say something about the use of ultra-violet rays in detecting forgeries and repairs of rare postage stamps, but had been prevented by indisposition.

He (Mr. Dow) had, however, a few exhibition pieces which Messrs. Harmer, the philatelic auctioneers, had placed at his disposal. The ultra-violet cabinet might be useful in facilitating the detection of forgeries of stamps, forged overprints on stamps and repaired stamps. Forgeries were most numerous and most expert in the case of old European stamps, but were occasionally found in the case of modern British Colonials. As an instance, he showed side by side a genuine £1 King Edward Sierra Leone stamp and a forgery—apparently used—of the same stamp, which was quite a good imitation. Under ultra-violet light, however, the colour of the fluorescence exhibited by the two was quite different, and the forgery was easily detected. Reprints, he demonstrated, could be distinguished from genuine Heligoland stamps in the same way. In some cases a forged overprint on a genuine stamp could be detected by the fact that the printing ink fluoresced in the wrong colour. In the case of old and valuable imperforate stamps, it was quite usual for repairs to be executed quite as skilfully as in the case of old furniture. A poor and close-cut copy could be improved by the addition of good margins; it was even possible to produce an apparently sound and fine copy by joining together portions of several defective stamps—and in such a way that the joining up might escape detection even under the microscope. It might be possible in such a case for the ultra-violet light to reveal what was imperceptible by visible light. As an example, he showed a rare stamp of Western Australia. To the eye this appeared perfect, but under the lamp the peculiar green fluorescence of the corners showed that these had been added to the original stamp. Other exhibits showed how pen cancellations on stamps, which had been washed out, again became visible when ultra-violet radiation was applied.

Communicated:—

If I may take advantage of the announcement at the meeting that additional queries would not be unwelcome, I would like to ask for information on some aspects of phosphorescence.

Can any indication be given of the improvement as regarded intensity and duration of phosphorescent effects during recent years? Is there an evident theoretical limit, or may we expect great future advances?

If one increases the stimulus, is the intensity of phosphorescence continually increased?—could one, by very intense stimulation with, say, cathode rays, produce a brightness far more vivid and lasting than is attained at present?—or is saturation quickly attained? If so, on what does the "storage capacity" really depend?

Is there any justification for the hope that ultimately we may be able to produce a substance with sufficient storage capacity to serve a really practicable purpose by night, e.g., for use in mines, docks and other dark places with the certainty that sufficient brightness to be of genuine service can be retained for, say, twenty-four hours?

Mr. J. T. RANDALL (*communicated*):—

I should like to say how interested I have been in all that Mr. Lamplough and others have had to say on the subject of ultra-violet light and its applications. My own interests, and those of the Research Laboratories with which I am associated, are naturally in the aspects of this problem that affect problems and achievements in the illumination field. Particularly, the problems we are most interested in are the applications of luminescent materials to discharge lamps. Dr. Levy has suggested that the zinc sulphides are perhaps the best luminescent materials, but I hope to be able to convince him that some of the other substances are equally important from the point of view of lighting. Mr. Lamplough

has told us something about this, and I should, in a moment, like to add a little to what he has said. There are first, however, one or two other points I wish to mention.

1. *Fluorescence and Phosphorescence.*

Mr. Lamplough has told us about *fluorescent* substances and *phosphorescent* substances. I wish to make a plea, perhaps a little unusual, for the use of an American term—viz., *luminescence*, as one describing the general phenomena. It is generally accepted, I think, that by fluorescence is meant the light emitted when the exciting radiation is incident to the material. By phosphorescence is meant the after-effect. There is no doubt that phosphorescence is, physically, the simpler of the two, since here already excited electrons only are returning to levels of lower energy. In fluorescence, which is of far more importance in the practical illumination fields, some electrons are being raised to new levels, and others are returning to old levels simultaneously. I think we have all been apt to use these terms rather loosely, and I think we ought to bear in mind their proper meanings.

Mr. Lamplough has mentioned the complexity of the luminescent spectra. According to the nature of the exciting radiation each band will be excited to different degrees. This is frequently seen with the sulphides. A powder that appears green under light of 3,000 A.U. may have a bluish tinge under the action of cathode-rays.

Physically speaking, I would class the substances that Mr. Lamplough has separated into sections 3 and 4 of his list as the same from the point of view of phosphorescence. Any substance which fluoresces will phosphoresce, but there may be huge differences in the time-factor. Calcium tungstate phosphoresces for only a few micro-seconds, whereas the sulphides Mr. Lamplough has told us about may glow for hours.

I think it is fairly certain that all inorganic compounds that luminesce do so in virtue of some impurity they contain, with one important exception. All the uranyl salts luminesce without the addition of an impurity.

Certainly the making of modern luminescent powders of high efficiency depends on the proper use of impurities in otherwise pure materials.

2. *Historical.*

Before coming to the application of luminescent powders to discharge lamps there are one or two points of historical interest. Mr. Lamplough has mentioned the first known discovery of luminescence —that of the "Bolognian Phosphorus." I note that he gives the date of this as 1602. I wonder if he could tell us the authority for this. In a copy of Priestley's "History of Vision" there is a very full account of this discovery, and the date is given as 1630. (The discoverer was Vincenzo Calcariolo.) He calcined a fossil found in the neighbourhood. The effect of heat in accelerating the phosphorescence was also noticed, and the well-known effects of moisture on the sulphide type round about 1765.

With regard to the effect of temperature which Mr. Lamplough has also demonstrated, some substances have their maximum luminescence at very low temperatures, such as, for example, the ruby; artificial rubies made by treating alumina with a chromium salt show this very well. Above room temperature most substances show a sharp decline in intensity of luminescence as the temperature is raised. The sulphides decline very rapidly, but some of the silicates are not so sensitive to temperature.

3. *Applications to Discharge Tubes.*

Mr. Lamplough has also told us that luminescent powders may be used, both to improve the efficiency and modify the colour of discharge lamps. Here, of course, I am talking of luminous efficiency in lumens per watt of the complete lamp, and not the intrinsic quantium efficiency of luminescence itself. In both cold and hot cathode discharge tubes of the positive column type filled with mercury-argon it is possible to obtain efficiencies at least five times as great as hitherto by coating the interior of the glass tube with the appropriate powder. At the same time the effective colour may be entirely changed.

Also it has recently been found at Wembley that Neon can also be used to excite the luminescence of these powders. Now powders luminescing in the yellow, green, and blue parts of the spectrum are more common than those giving out light in the red. By using neon in conjunction with luminescent powders it is possible to obtain high voltage tubes of a colour suitable for interior lighting of an efficiency appreciably higher than that of the tungsten filament lamps. Mr. Jenkins will demonstrate these applications to you.

So far I have mentioned only the low pressure long positive column type of tube. I now wish to say a few words about the high pressure type of mercury lamp in use for street and factory lighting. These, as everyone knows, are deficient in red radiation. Can a red luminescent powder be used successfully to increase the percentage of red radiation? It is impossible to coat the interior of the discharge lamp itself because of the high temperature. This would be sufficient to decompose the powder under the action of the discharge; even if this were not so the luminescence would be impractically weak because of the temperature effect already mentioned.

As Mr. Lamplough has mentioned, the reflectors may be coated with luminescent material. One of the older ideas was to use rhodamine, but this had not been found very satisfactory. Rhodamine is an organic dye, which tends to decompose under strong illumination and lose its luminescence. For some time the Wembley Laboratories have been experimenting with other materials and other methods. We have, I think, achieved considerable success by coating the inside of the outer jacket of the high pressure lamps with red-luminescent powders of more stable nature. It has been possible to improve the percentage of red light from the whole unit to 6 per cent. with very little loss of efficiency. An installation of these lamps is actually running in one of our factories.

I should explain here that only those powders excited by the near ultra-violet can be used, since the

glass of the lamp proper transmits only these. In any case, at high pressures the proportion of very short-wave radiation is very small.

Where the temperature of the lamp is low, the powders can naturally be placed in contact with the discharge.

On the chemical side I might mention that quinine has frequently been used as an indicator. In our own laboratories, the difference between the luminescence of lubricating oil and fuel oil has been used to distinguish the source of the carbon in a Diesel engine.

Although I do not think the results have yet been published in sufficient detail, it should be said that considerable doubt has now been thrown on the luminous efficiency of the firefly. By imitating the chemi-luminescence of this insect in a test tube, a luminous efficiency of about 5 lumens per watt is stated to have been obtained in the United States.

Dr. LEONARD LEVY (*communicated*):—

The following are my comments on the points that Mr. Dow raised:

(1) *Improvement in intensity and duration of phosphorescent effects.*

Whilst the intensity of fluorescence for certain substances has been increased, in some cases several times, there is little or no improvement in phosphorescence. This may be due to the fact that phosphorescence is less valuable a property and has not received the same degree of attention as the fluorescent effects. The fact remains, however, that such attempts as have been made have not led to any material improvement.

(2) *Variation of intensity with stimulus.*

Certain luminescent preparations show saturation effects so far as fluorescence is concerned, whereas others of almost identical composition do not become saturated until a much higher intensity of incident radiation is reached. The cause of this is at present unknown. Under intense stimulation by cathode rays the brilliance of fluorescence can be increased to a very high order, but so far as I am aware the phosphorescence is but little affected.

(3) *Possibility of the production of a phosphorescent substance of practical storage capacity.*

In view of our experience up to date I think it is unlikely that a phosphorescent substance would be produced capable of giving any illumination worth having for twenty-four hours. The intensity of illumination decays exponentially and would need to be extremely intense at the commencement. Calcium sulphide, the earliest known of all luminescent substances, is about as good as anything so far as the duration of phosphorescence is concerned; not any of the numerous luminescent substances since produced are superior to it so far as this property is concerned.

Mr. F. E. LAMPLOUGH, in reply:—

With reference to Mr. Randall's remark on terminology, from the academic standpoint I agree there is use for a general term luminescence; when, however, one is not splitting hairs and dealing with thousandths of a second of after-glow, the terms fluorescence and phosphorescence are useful in the broad description of different phenomena.

The statement on the history of the first known discovery and production of phosphorescent material was on the authority of Prof. R. W. Wood's "Fluorescence," Encyc. Britt., but no reference is given.

The use of rhodamine as a fluorescent material in conjunction with mercury vapour lamps is certainly subject to the disadvantage of fading. Some years ago a representative of makers of such lamps for factory use made a virtue of a necessity, and pointed out that the undesirable excess of green in a new installation could be modified by the use of this fluorescent material, and that as the effect gradually faded the workers became accustomed to and tolerant of the ordinary light of the lamp.

Forthcoming Events.

May 12th.—The **Annual Meeting** of the Illuminating Engineering Society. After the Presentation of the Annual Report and Accounts, and the Transactions of Formal Business, an **Address** will be delivered by Dr. MERRY COHU (Paris) on **"Some Aspects of the Question of Reflection from Road Surfaces and Notes on Development in Lighting in France."** *(At the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W.1);* **7 for 7.30 p.m.**

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

NOTES ON RECENT MEETINGS AND EVENTS

The Annual General Meeting.

The annual general meeting was held in the Lecture Theatre of the Institution of Mechanical Engineers on Tuesday, May 12, when the Report of the Council and accounts for the past session were approved, and the auditors were elected for the forthcoming year.

The report and accounts will be published in the "Transactions" in due course, and will be accompanied by an account of the proceedings at the above meeting.

Following these proceedings an ordinary general meeting of the Society took place. The minutes of the last meeting having been taken as read, the names of applicants for membership were presented in the usual way.

An Address by Dr. Merry Cohu.

The President then called upon Dr. Merry Cohu to deliver his address on "Some Aspects of the Question of Reflection from Road Surfaces and Notes on Developments in Lighting in France." Dr. Cohu described, by the aid of numerous lantern slides, his experiments on road surfaces, and in conclusion showed a series of lantern slides illustrating lighting installations in Paris.

Dr. Cohu having replied to various questions asked by members of the Society, a cordial vote of thanks to him for his address terminated the proceedings.

APPLICATIONS FOR MEMBERSHIP

Elections Pending.

At the general meeting of the Society, held on May 12, 1936, the names of the following applicants for membership were presented:—

CORPORATE MEMBERS:—

Besemer, B. F. W. ... 20, Townsend Avenue, Old Southgate, LONDON, N.14.
Crowther, D. E. ..... 26, Woodfall Street, Chelsea, LONDON, S.W.3.
Gerard-Boulton, A. ... 5, Bute Street, LONDON, S.W.7.
Grammer, J. M. ..... 37, Broadfields Avenue, LONDON, N.21.
Lloyd, W. H. ..... 29, Marlborough Road, Richmond, SURREY.
Marshall, F. M. ..... 81, Gordon Road, Ealing, LONDON, W.
Nisbet, T. ..... 15, Walmer Crescent, GLASGOW, S.W.1.
Poulter, L. C. S. ..... 17, Vallies Way, Ealing, LONDON, W.
Robinson, C. C. H. .... 23, East Prescot Road, Knotty Ash, LIVERPOOL, 14.
Stevens, C. J. ..... 5, Pinner View, Harrow, MIDDLESEX.
Wayman, A. R. ..... 27A, Redington Road, Hampstead, LONDON, N.W.3.
Wynne, F. W. ..... 307-11, High Road, Kilburn, LONDON, N.W.

COUNTRY MEMBERS:—

Anderson, J. M. ..... 214, Ashdale Drive, Mosspark, GLASGOW.
Cartwright, T. D. ..... 195, St. Vincent Street, GLASGOW.
Cassels, T. M. ..... 29, St. Vincent Place, GLASGOW.
Coulehan, J. C. ..... 19, Percy Street, HULL.
Ewing, J. ..... Lighting Department, 20, Trongate, GLASGOW, C.1.
Fischer, J. ..... P.O. Box 434, Jerusalem, PALESTINE.
Forbes, H. S. ..... 39, Dorain Drive, Clarkston, RENFREWSHIRE.
Harris, W. J. ..... 86, Kirkcaldy Road, GLASGOW, S.
Hood, E. M. ..... 140, West George Street, GLASGOW, C.2.
Hurd, C. F. ..... 25, Camphill Avenue, Langside, GLASGOW.
Langlands, J. S. ..... 1413, Pollokshaws Road, GLASGOW, S.1.
Lappin, T. M. ..... Lighting Department, 20, Trongate, GLASGOW, C.1.
McAllister, R. ..... 53, Pitt Street, GLASGOW.
MacKerron, H. G. .... 128, North Street, GLASGOW.
Mann, J. M. ..... Lighting Department, 20, Trongate, GLASGOW, C.1.
Mitchell, W. ..... 74, Waterloo Street, GLASGOW, C.2.
Rankin, A. M. ..... 20, James Street, GLASGOW, S.E.
Raphael, R. A. ..... 166, Buchanan Street, GLASGOW, C.1.
Tait, H. A. ..... 15, Slateford Road, EDINBURGH.
Tulloch, M. M. ..... Anglo Oriental (Malaya), Ltd., Tanjong, Toalang, PERAK, F.M.S.
Yuille, W. ..... "Dinard," Bulloch Avenue, Giffnock, RENFREWSHIRE.
Welsh, J. ..... 167A, St. Vincent Street, GLASGOW.

ASSOCIATE:—

Raffé, W. G. ..... 56, Gloucester Crescent, Regent's Park, LONDON, N.W.1.

Elections Completed.

At this meeting the names of those announced on April 7, which were published in the last issue of the "Transactions" (Vol. I., No. 5, p. 68, May, 1936), were read again, and these applicants were formally declared members of the Society.

THE CLASSIFICATION OF SYMMETRICAL LIGHT DISTRIBUTIONS

by H. BUCKLEY, M.Sc., F.Inst.P. (National Physical Laboratory) *(Member)*

(Paper read at the Meeting on Tuesday, February 11th, 1936.)

The subject dealt with in this paper was proposed at the Bellagio meeting of the International Commission on Illumination in 1927 as one which merited study from an international standpoint. In the terms of reference the subject was referred to as "The Distribution of Luminous Flux from Lighting Fittings," and the Belgian National Committee was invited to study the subject, to act in a secretariat capacity to the other national committees, and to make proposals specifying standard zones for the definition of the distribution of luminous flux from lighting fittings.

That the subject is important must at once be admitted. Difficulties have often arisen and will often arise in the comparison of the lighting equipment supplied by different manufacturers, so long as there exists no generally accepted methods by which the performance and characteristics of such equipment can be described.

1928 Meeting of the I.C.I.

The next meeting of the Commission took place in America in September, 1928, so that there was not much time available for the Belgian Committee to get into touch with the other national committees. At this meeting, however, three interesting papers on the subject were given.

The first, by Yamauti (1), described point-to-point methods of determining zonal flux.

The second, by Desarces and Demeure (2), proposed that lighting fittings should be described by the manner in which the luminous flux they emit is distributed among zones of, say, 10 degrees; this distribution being compared with that of a so-called "standard" fitting which fulfils the condition that the illumination on the working plane between two lighting units shall be as uniform as possible. It was also proposed that the maker, in adition to giving the polar curve of luminous intensity and stating the spacing-height ratio at which it should be used, should also specify the flux distribution among the zones, so that the purchaser could easily make a comparison with the standard by consulting a label and a diagram in the maker's catalogue.

The third, by Wetzel (3), discussed the possibility of assessing the performance of a fitting from the point of view of the uniformity of the illumination attainable by its use. Wetzel considered that the question of flux distribution had two aspects, the first in connection with the *type of lighting* which was required, and the second in connection with the *uniformity of illumination* which was required. He was of opinion that for the first aspect, classification based on the percentage of flux in the lower or upper hemisphere was sufficient, while for the second a classification based on the actual distribution of flux in each hemisphere was necessary. His method of classification was based on the determination of the coefficient of uniformity for different spacing-height ratios. No further work appears to have been carried out in this direction, however.

At the same meeting the British delegates reported that the British committee did not consider that a method of defining light flux distribution in terms of the luminous flux emitted in standard zones could be usefully adopted for general purposes. They proposed a classification (4) based on a consideration of the total solid angle into which a certain agreed proportion of the flux was distributed, as shown in the following table:—

Classification No.	Type	Agreed Proportion of Flux in Solid Angle. (Angle in steradians)
0.1	Projecting	0.01— 0.1
1.0	Concentrating	0.1 — 1.0
2.0	Intensive	1.0 — 2.0
4.0	Dispersive	2.0 — 4.0
6.0	Extensive	4.0 — 6.0
8.0	Distributive	6.0 — 8.0
12.5	Semi-controlling	8.0 —12.5

This method did not meet with the approval of the French and German delegates, who considered that the concept of solid angle was too difficult of apprehension by the average user and that the classification number gave no idea of the candle-power distribution curve.

As a result of the meeting, a questionnaire (5) was drafted, the answers to which were to form the basis of discussion at the next plenary meeting of the Commission in 1931. The first two questions were as follows:—

1. What are the terms in use (in your country) for the classification of lighting equipment on the basis of the general character of their light distribution (terms such as direct, semi-direct, etc.)?

2. How are these classes further sub-divided to define the light distribution more definitely (terms such as intensive, extensive, etc.)?

Work of the British Committee (1928-1931).

These two questions correspond to a division of the problems of classification of distributions into two parts. Quite early the British Committee had realised that certain terms in use in many countries were used in an undefined way which were, however, intended to give general impressions of the various types of light distribution. In the British Committee's opinion the problem of classification consisted in the definition of these terms.

This division of the problem corresponded also to the ideas put forward by Wetzel in the paper previously

mentioned, and corresponded also to the two problems which the illuminating engineer has to solve in planning a lighting system, viz.:—

(1) What proportion of the flux shall be directed on to the ceilings?

(2) What height-spacing ratios are best with the light distributions available, or alternatively what light distributions are most suitable for the convenient height-spacing ratios?

The first part of the classification was accomplished without much difficulty. The terms indirect, semi-indirect, semi-direct, and direct as applied to distributions, were defined with regard to the division of the flux in the upper and lower hemispheres as follows:—

Class.	Definition.
Direct	More than 90% in the lower hemisphere.
Semi-direct	More than 50% and less than 90% in the lower hemisphere.
Indirect	More than 90% in the upper hemisphere.
Semi-indirect	More than 50% and less than 90% in the upper hemisphere.

It was later found desirable to include a further type, due to the use of totally enclosed fittings having light distributions with about 50 per cent of the flux in either hemisphere. It was felt desirable to include this type of distribution, as from the point of view of numbers of fittings having this distribution, it appeared to be one of the most important types in use. The final classification arrived at was as follows:—

Class.	Definition.
Direct	Not less than 90% of the total flux in the lower hemisphere.
Semi-direct	More than 60% and less than 90% of the total flux in the lower hemisphere.
General	Not less than 40% or more than 60% of the total flux in either hemisphere.
Semi-indirect	More than 60% and less than 90% of the total flux in the upper hemisphere.
Indirect	Not less than 90% of the total flux in the lower hemisphere.

This classification was regarded as the main classification based on considerations of flux alone, and indicated by means of very familiar terms the type of lighting for which the distributions were suitable.

The second subsidiary classification which was to indicate the general character of the distribution curve by means of familiar terms was more difficult of accomplishment. A very great deal of work was carried out by the sub-committee in the examination of a number of proposals for this secondary classification. It will be sufficient to state here that none of them was found to be really practical, although several had considerable merit in certain directions. Finally, the method which was ultimately adopted was proposed.

This method which was at first called the "box ratio" method, and later the "frame ratio" method consists in taking the polar curve of a light distribution in either the upper or lower hemisphere depending on which contains the major portion of the flux and drawing a rectangle whose sides are parallel to the 0° radius vector and to the 90° radius vector of the polar curve so as to completely enclose the polar

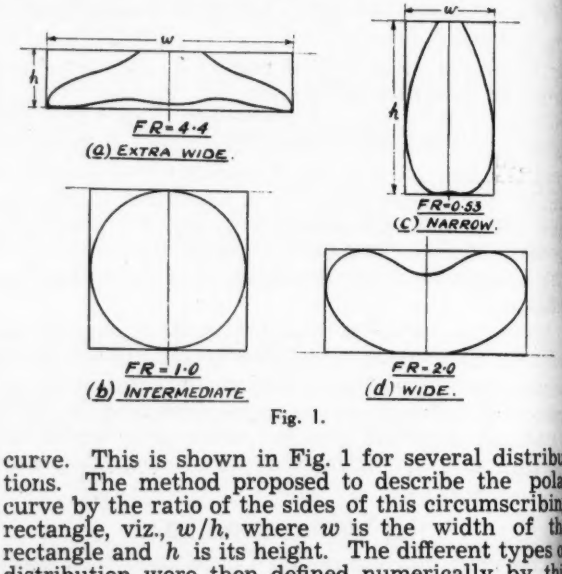

Fig. 1.

curve. This is shown in Fig. 1 for several distributions. The method proposed to describe the polar curve by the ratio of the sides of this circumscribing rectangle, viz., w/h, where w is the width of the rectangle and h is its height. The different types of distribution were then defined numerically by this ratio.

A further use of this method is that if a series of limits of frame ratios be fixed, distributions can be classified according to their frame ratios, and a nomenclature already in use to some extent can be associated with numerical values. Thus, for example, all distributions whose frame ratio lies between the values x and y can be termed "intensive" distributions, while those between y and z can be called "distributive."

These terms have already been used to describe certain light distributions, and have usually been associated, somewhat loosely in some cases, with the spacing-height ratios at which fittings having these distributions will produce substantially uniform illumination on the working plane. Neither the spacing-height ratio nor the uniformity produced have, however, been regarded as being more than approximately defined by the use of these terms.

The first classification on this method considered by the Committee was the following:—

	General Character.	Frame Ratio Limits
(1)	Concentrating	0.2—0.4
(2)	Focussing	0.4—0.8
(3)	Intensive or Dispersive	0.8—1.6
(4)	Extensive	1.6—2.2
(5)	Distributive	2.2—3.5
(6)	Extra Distributive	> 3.5

On this system the types of distribution called by the Germans, Tiefstrahler, Breitstrahler, Freistrahler and Flachstrahler fall into the groups 3, 4, 5 and

respectively. In this connection it is perhaps worth while mentioning that the frame ratio was originally suggested by consideration of these German names. It was suggested that two of the names, at any rate, seemed to be connected with the width of the rectangle circumscribing the polar curve, though this is not, of course, the actual origin of these names.

It was not possible to agree to the use of these terms in the manner suggested, as various manufacturers had used these terms for many years without any very precise definition, and in certain cases it would have meant that the names had to be changed. The names and subdivisions were then reconsidered in conjunction with a large selection of polar curves of fittings which were actually on the market, and the following classification was arrived at:—

General Character.	Term.	Frame Ratio Limits.	Zones of Max. C.P.
I.	Extra Narrow	0.00—0.18	0°— 5°
II.	Narrow	0.18—0.80	0°—24°
III.	Intermediate	0.80—1.40	0°—45°
IV.	Wide	1.40—3.00	0°—90°
V.	Extra Wide	3.00—	48°—90°

These terms have a very obvious connection with the dimensions of the circumscribing rectangle. The extra column was introduced to meet the desire of a number of persons: that the angle at which the maximum candle-power occurs should be given as well in any description of a distribution in terms of the frame ratio.

As a matter of fact, the angle of maximum intensity is controlled to a certain extent by the frame ratio. Thus in Fig. 2a, which illustrates a frame surrounding a distribution of frame ratio less than 2, the angle of maximum candle-power, if the polar curve is to touch the horizontal and vertical sides of the rectangle cannot be at an angle to the vertical greater than θ, where

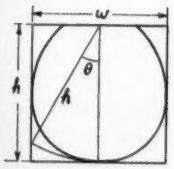

Fig. 2(a).

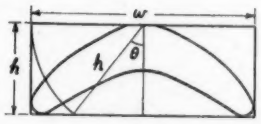

Fig. 2(b).

$$\sin\theta = \tfrac{1}{2}\, w/h = \frac{\text{Frame Ratio}}{2}$$

i.e. θ not greater than $\sin^{-1} F/2$

where F is the frame ratio.

Similarly for distributions whose frame ratio is greater than 2 as in Fig 2b the angle of maximum candle-power cannot be inclined to the vertical at an angle less than θ, where

$$\cos\theta = h/\tfrac{1}{2}w = \frac{2}{\text{Frame Ratio}}$$

i.e. θ not less than $\cos^{-1} 2/F$

The figures in the table were obtained from these formulæ. With these limitations on the possible angles of maximum candle-power, the specification of this angle is not so important.

In Fig. 3 the angles of maximum candle-power are shown as ordinates with frame ratios as abscissae.

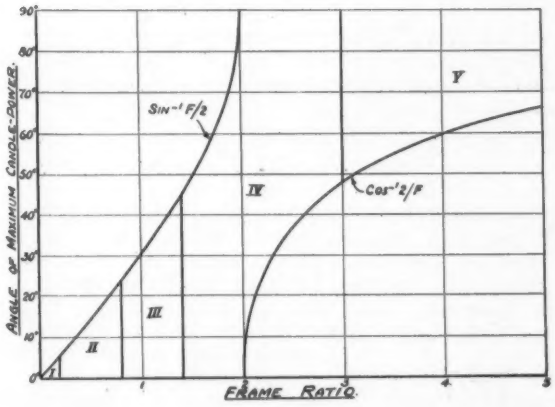

Fig. 3.

The two curves, $\theta = \sin^{-1} F/2$ and $\theta = \cos^{-1} 2/F$ show the limits of the angle of maximum intensity for each value of the frame ratio.

During the progress of the discussions on the frame ratio method, exception was taken because, given the frame ratio, one could not draw the polar curve, and that for the same frame ratio different polar curves could be drawn. It was finally agreed that to expect this from any classification system based on the use of a single quantity, such as the frame ratio, was expecting too much of any system. After all, what was wanted was a system which would put into the same class distributions which had something in common. The terms which were already in use did not achieve this object either, as no one could draw a distribution which was alleged to be of the dispersive type and expect it to be identical with that drawn by some one else.

It appeared on investigation, however, that while different distributions could be drawn having the same frame ratio, the illumination results obtained from these different distributions were not very different. For example, an attempt was made to correlate the frame ratio with the angle of maximum vertical illumination for the distributions shown in Fig. 4.

If the distribution be C_θ where C_θ is the candle-power in the direction θ, then the vertical illumination ($C_\theta \cos^2\theta \sin\theta$) and the angle of maximum vertical illumination can be found either by plotting, or mathematically by differentiation, if C_θ is expressed as a mathematical function. The results

found for this investigation are given in Fig. 5, from which it appears that there is a fairly high correlation between the two. A similar fairly high correlation was found when the frame ratio was plotted against the angle at which the horizontal illumination ($C_\theta \cos^3\theta$) falls to one half its maximum value, as shown in Fig. 6. Thus the frame ratio does correlate to some extent with the illumination performance of the distributions.

As a result of these considerations the frame ratio method was incorporated in the British Standard Classification of symmetrical light distributions from lighting fittings (6) published in October, 1930.

Paraphrasing the specification, symmetrical light distributions whose axes are regarded as vertical shall be classified:—

(a) by one of the terms Direct, Semi-direct, General, Semi-indirect, or Indirect, as defined on page 84, to indicate the class of lighting for which the distribution is intended; and

(b) by one of the terms Extra Narrow, Narrow, Intermediate, Wide, Extra Wide, or the corresponding number, as defined above, to indicate the general character of the polar curve of the light distribution in a plane containing the axis of symmetry of the light distribution.

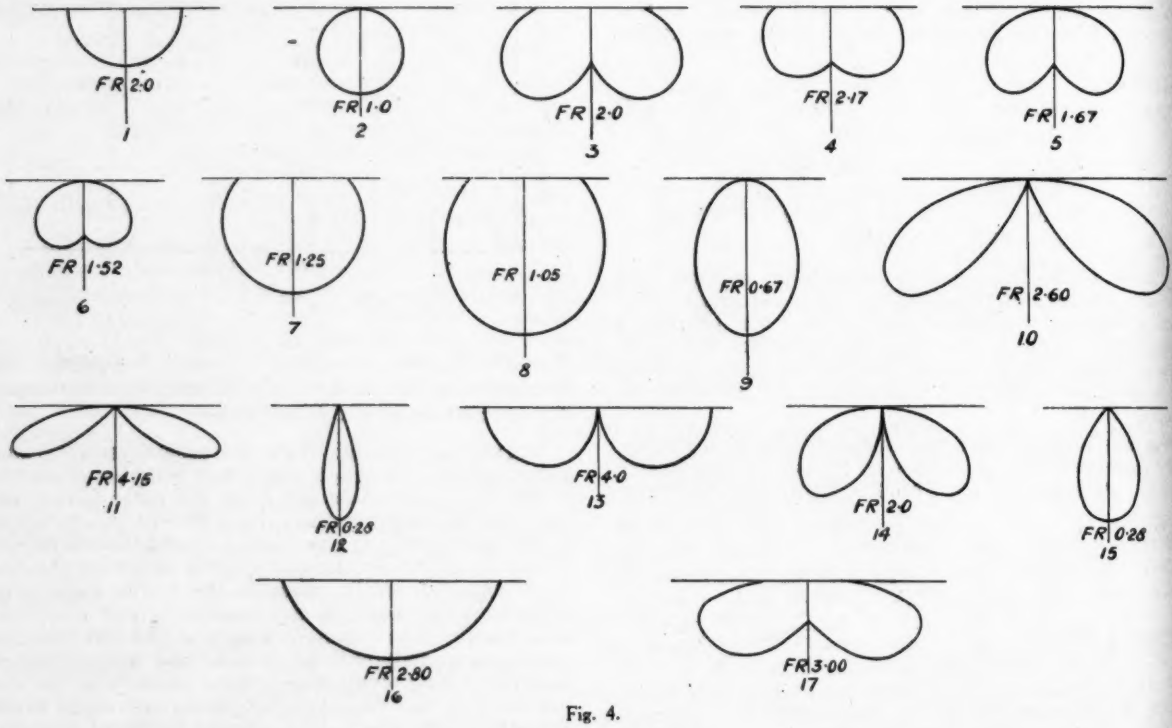

Fig. 4.

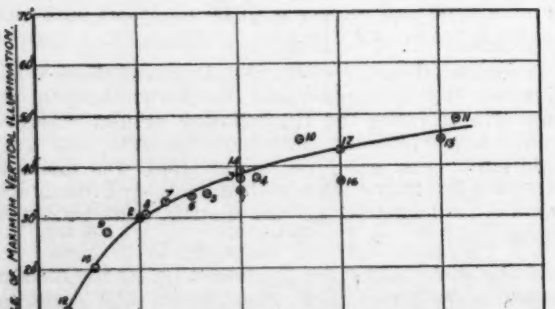

Fig. 5.

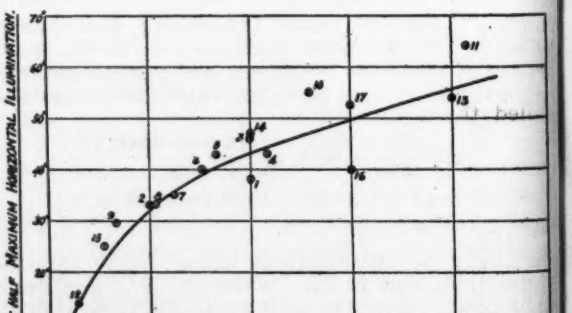

Fig. 6.

If specially desired, the direction of maximum candle-power may be given, but such additional information is not necessary from the point of view of the specification itself."

On this system the distribution illustrated in Fig. 1 would be classified as follows:—

(a) Direct, Extra Wide or Direct, Class V.
(b) Direct, Intermediate or Direct, Class III.
(c) Direct, Narrow or Direct, Class II.
(d) Indirect, Wide or Indirect, Class IV.

1931 Meeting of the I.C.I.

At the plenary meeting of the I.C.I. in 1931, held in Cambridge, the Belgian report (7) incorporating the replies of the various national committees to the questionnaire was considered. As regards the use of the terms, direct, semi-indirect, etc., it appeared that all countries used the terms direct, semi-indirect, and indirect, and that it would be useful to add the terms, semi-direct and general.

The Belgian Committee then proposed for international adoption definitions of these terms, in agreement with those arrived at by the British Committee. Agreement was reached that the primary method of classification should be based on the partition of the luminous flux in the upper and lower hemispheres, and that the five terms proposed should be used. Agreement in the actual percentages defining these terms was not, however, reached.

The replies to the question on the use of such terms as intensive, etc., to denote the general character of the distribution in a hemisphere, showed that the terms, intensive and extensive (or their equivalents) were used in all countries, but they were not by any means precisely defined.

The meeting also examined the proposals put forward by the French National Committee (8). These were based on the angle within which the major portion of the flux was concerned, viz.:

$<20°$ hyperconcentrating.
$<30°$ concentrating.
$<40°$ intensive.
$<50°$ semi-extensive.
$<60°$ extensive.
$>60°$ hyperextensive.

The Japanese National Committee also submitted a method of classification prepared by Yamauti and Hisano (9). In this method, a numerical expression called the "flux distribution number" is derived, which makes it possible to imagine the general mode of flux distribution of symmetrical fittings. Suppose that $\alpha \times 10$ per cent. of the total flux is emitted in the upper hemisphere, $\beta \times 10$ per cent. in the upper half zone of the lower hemisphere, $\gamma \times 10$ per cent. in the upper half zone of the remaining half of the lower hemisphere, and so on. If the rounded-up integers of $\alpha,\beta,\gamma \ldots$ be a.b.c. . . respectively, then the flux distribution number is a.b.c. The first figure (a) is called the class number. Symmetrical distributions can be classified by the class number into indirect, semi-indirect, semi-direct, and direct types. Distributions of the direct class can be further classified into spread, distributive, extensive, intensive, concentrating, and projecting types depending on the flux distribution number.

The classification based on class number is, of course, very similar to that used in other countries for the definition of the terms, direct, etc. In the Japanese proposals these terms are defined as follows:—

Class Number.	Type.
9 and 10.	Indirect.
6, 7, and 8.	Semi-indirect.
3, 4, and 5.	Semi-direct.
0, 1, and 2.	Direct.

The relation between various distributions was shown in a triangular co-ordinate system whose co-ordinates were $\alpha \times 10$, $\beta \times 10$, and $(\gamma + \delta + \ldots) \times 10$.

The Japanese proposals were only received just prior to the meeting, so that they had not been studied in very great detail before the meeting. A criticism was made that the number apart from the first, corresponding to the most important zone, appeared last in the composite number a.b.c . . . expressing the distribution.

German proposals, by Mr. Schneider (10), which had been discussed at a meeting of the International Illumination Congress a few days before, were also discussed. His proposals were based on consideration of the percentage of flux in the upper and lower hemispheres, and also the percentage of flux in the 0°—60° zone, and resulted in the classification given below.

Name	% of flux in lower hemisphere	% of flux in zone 0° — 60°
Direct		
Group I.	100	80
Group II.	100	60—80
Semi-direct		
Group I.	65—80	40—60
Group II.	50—65	30—40
Group III.	50—60	25—30
Semi-indirect	10—50	
Indirect	0—10	

In the discussion, criticisms were made about Group III. of the semi-indirect type, and Mr. Schneider agreed to look into the possibility of changing it. It was finally agreed that the principal classification should be based on the use of the five following subdivisions, indirect, semi-indirect, general, semi-direct, and direct, and that the various methods proposed should be the subject of further study.

Work of the British Committee (1931-1935).

After the 1931 meeting, the British Committee made efforts to get closer agreement with the German proposals. It was pointed out that the German proposals did not include every possible type of distribution, and that it was not symmetrical in the way

that the British proposals, and, incidentally, the proposals of the Belgian Committee were. Mr. Schneider had already agreed to transfer his Group III. to a general class, as a result of discussions at Birmingham and Cambridge.

Nothing further was done in connection with the frame ratio proposal until the specification for the dispersive reflector was revised in 1934. The original classification (11) had included a candle-power requirement at certain angles. The new proposal was that the distribution should be of the type, direct, intermediate, which implies a frame ratio of from 0.8—1.4. In a note to the original specification it was stated that the specified distribution was suitable for installations in which the spacing of the lamps is one and a half times the height. This was omitted in the new classification (12). Later it was suggested that the best spacing-height ratio might be specified for each value of frame ratio, or for each range of fram ratios defining the various types of distribution. This problem was referred to the sub-committee dealing with Classification of Light Distributions.

The first matter considered in this connection was the criterion on which the spacing-height ratio should be specified. The sub-committee were unanimous in thinking that it was unnecessary to strive for perfectly uniform illumination, and that the higher the average illumination the less the uniformity ratio might be. It was finally decided that when the average illumination was 20 f.c. or over, a uniformity ratio of 50 per cent. was sufficient, but when the average illumination was lower, the uniformity ratio should be 70 per cent. This conclusion was based on examination of modern practice and the experience of members of the sub-committee.

In particular, calculations of the illumination from an infinite system of dispersive reflectors showed that, with the fittings placed at the corners of a system of squares, the uniformity ratio varied with the spacing-height ratio, as shown in Fig. 7. The polar curve for the calculations was taken as a circle

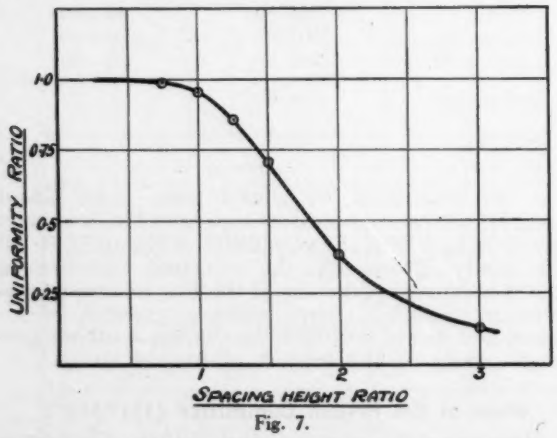

Fig. 7.

from 0°—70°, falling to zero at 90°. Actual dispersive reflectors give a little more than the circle distribution from 50°—60°, and a little less from 60° to 70°. The uniformity ratio was taken as the ratio of the illumination at points under the centres of the squares formed by four lamps to that at points under lamps. The curve shows that at the usual spacing-height ratio of 1.5 the uniformity ratio achieved with this reflector is about 70 per cent.

Members of the committee then agreed to consider what spacing-height ratios were suitable for distributions having various frame ratios.

As a result of the members' work the results shown in Figs. 8 and 9 were obtained. These show spacing-height ratios which give uniformly ratios of 70 per cent. and 50 per cent. respectively, plotted against the corresponding frame ratios for the dis-

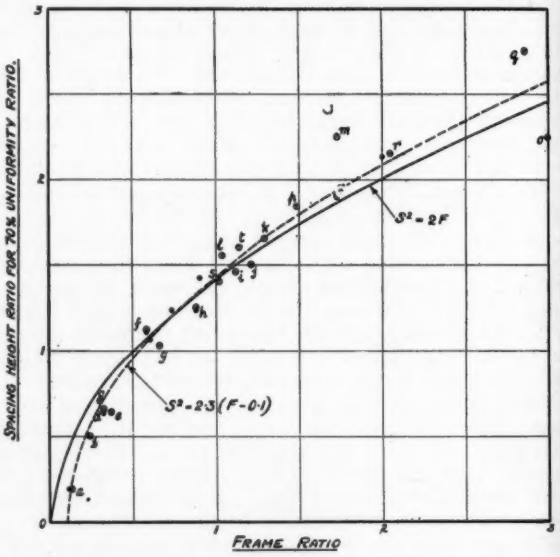

Fig. 8.

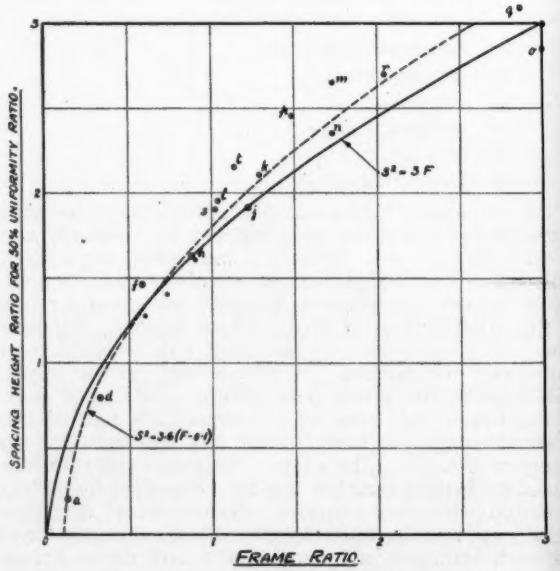

Fig. 9.

tributions shown in Figs. 10 and 11. The illumination was considered for infinite systems in which the light sources were at the corners of square and was calculated for points under lamps and at the mid points of units of the system, i.e., four lamps at the corners of a square. The illuminations and uniformity ratios were calculated for different spacing-height ratios from 0.5 to 2.5. The variation

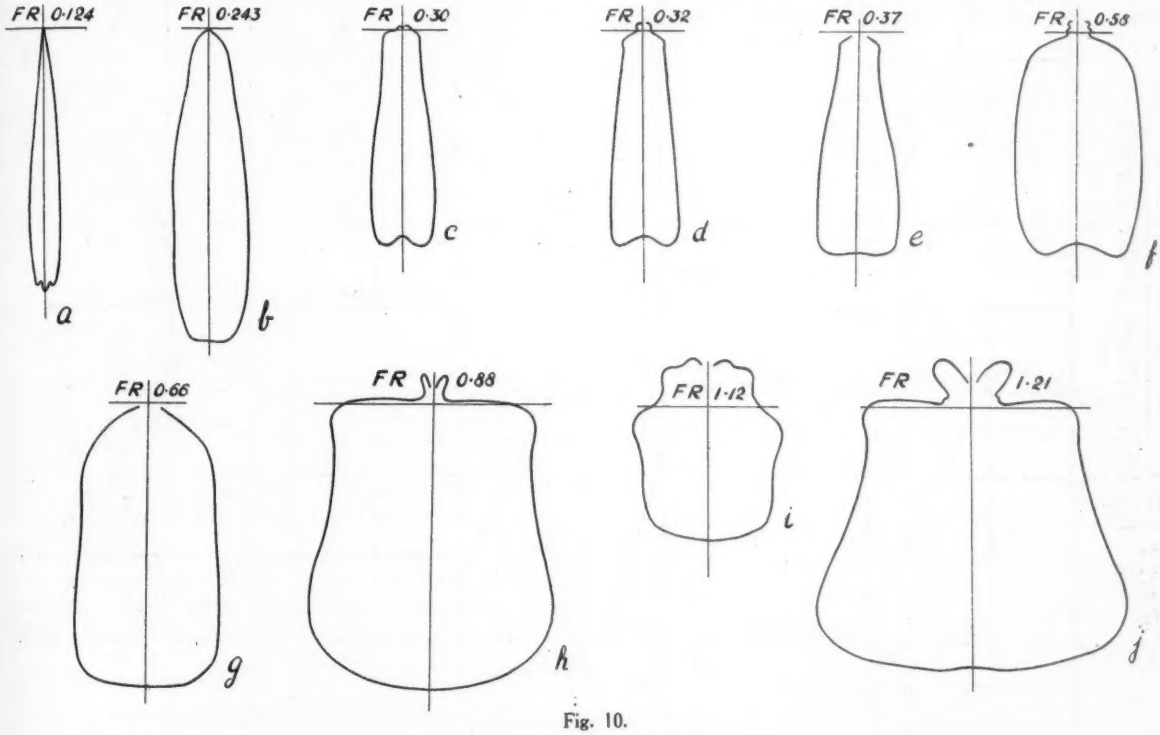

Fig. 10.

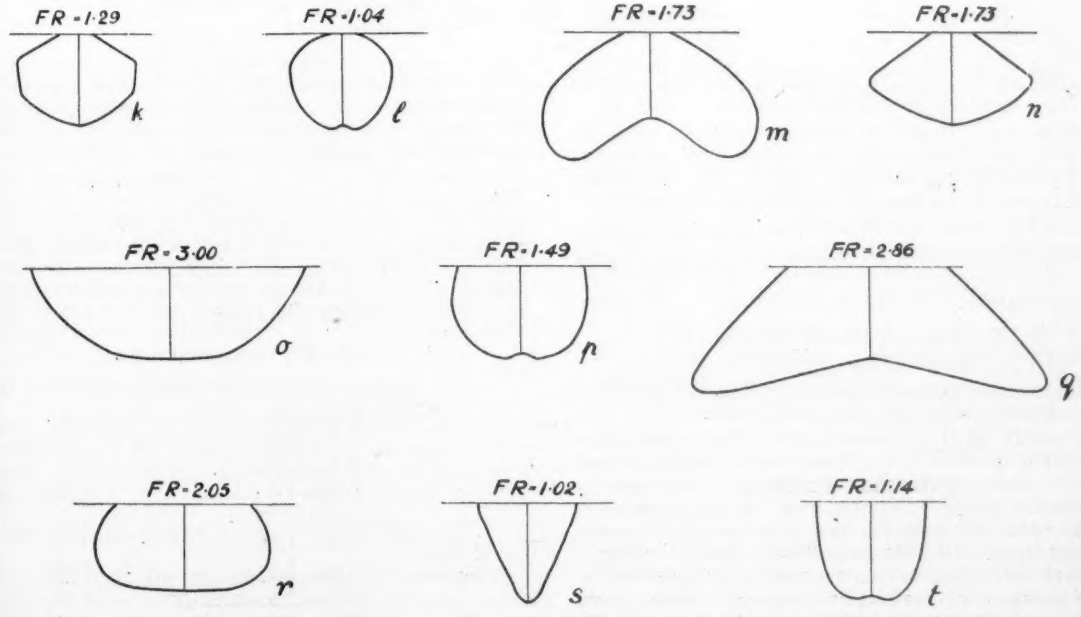

Fig. 11.

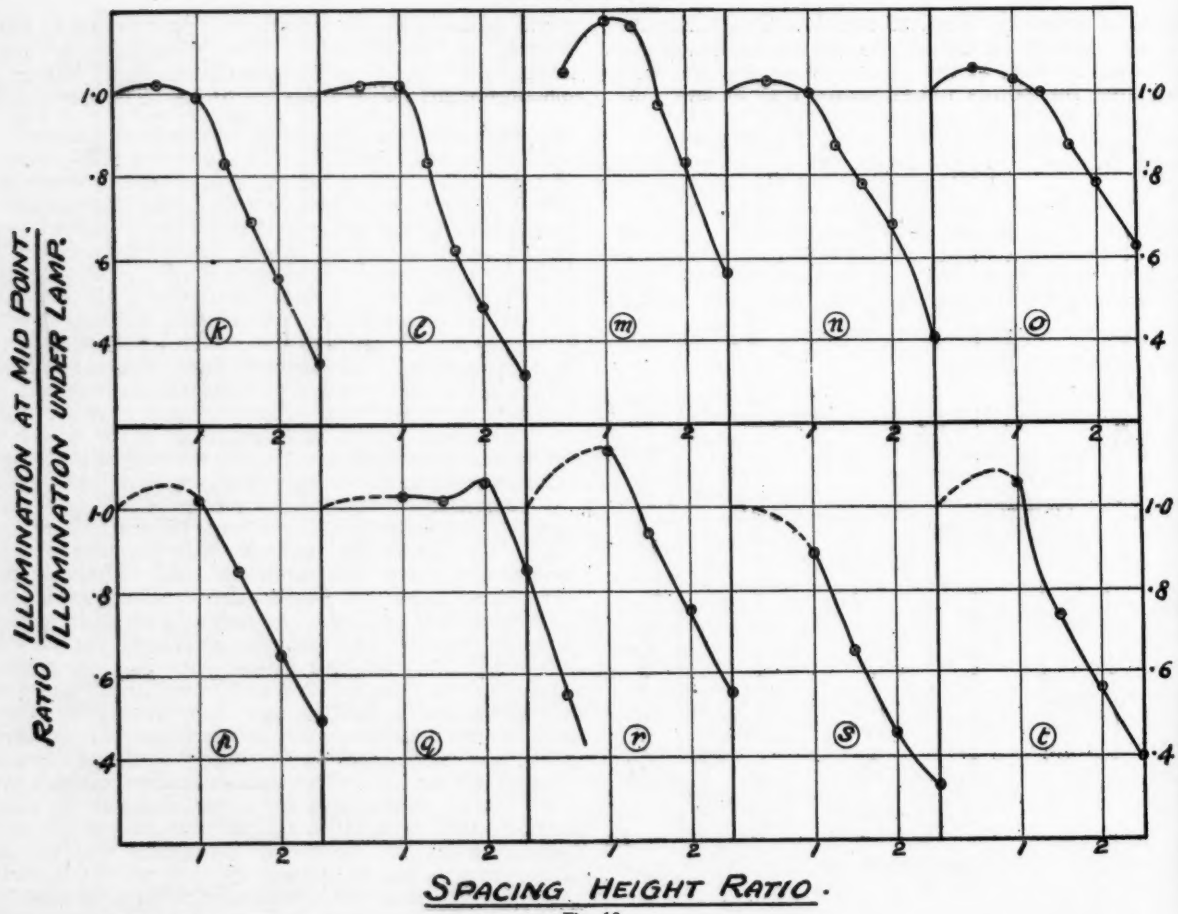

Fig. 12.

of the uniformity ratio with spacing-height ratio is shown for a number of the distributions in Fig. 12.

It will be seen that the relation between spacing-height ratio and frame ratio can quite well be represented by the curves in Figs. 8 and 9. The equations to the curves which best fit the observations are:—

$s^2 = 2.3$ (F—0.1) for 70 per cent. uniformity ratio.

$s^2 = 3.6$ (F—0.1) for 50 per cent. uniformity ratio.

or approximately:—

$s^2 = 2F$ for 70 per cent. uniformity, and

$s^2 = 3F$ for 50 per cent. uniformity ratio.

The former curves are shown by the dashed lines and the latter curves by the full lines.

As a result of this investigation the committee felt that the usefulness of the frame ratio method was considerably increased. Formerly it had merely served to classify distributions on a somewhat arbitrary plan, but gave no useful information in any other direction. In this it suffered from the same fault that all the systems considered previously suffered from, viz., that, apart from a classification, nothing further was accomplished. Consequent on the committee's work it was felt that a system of classification was possible which also gave fairly accurately the spacing-height ratio at which the distributions should be used in order to achieve particular values of the uniformity ratio. These results were then incorporated in the new classification (13), which was under preparation, by the addition of the two following tables, which give the spacing-height ratios for distributions of various frame ratios in order to obtain uniformity ratios of 70 per cent. and 50 per cent.

For 70% Uniformity Ratio

Frame Ratio			Spacing-Height Ratio.
Above 0.15—0.3	...	...	0.5
„ 0.3 —0.5	...	...	0.75
„ 0.5 —0.75	...	...	1.0
„ 0.75—1.0	...	...	1.25
„ 1.0 —1.33	...	...	1.5
„ 1.33—1.66	...	...	1.75
„ 1.66—2.1	...	...	2.00
„ 2.1 —2.5	...	...	2.25
„ 2.5 —3.0	...	...	2.50

For 50 per cent. Uniformity Ratio

	Frame Ratio.			Spacing-Height Ratio.
Above	0.15—0.25	...	...	0.5
„	0.25—0.35	...	...	0.75
„	0.35—0.5	...	...	1.0
„	0.5 —0.7	...	...	1.25
„	0.7 —0.9	...	...	1.5
„	0.9 —1.2	...	...	1.75
„	1.2 —1.5	...	...	2.0
„	1.5 —1.8	...	...	2.25
„	1.8 —2.2	...	...	2.5
„	2.2 —2.7	...	...	2.75
„	2.7 —3.2	...	...	3.0

McWhirter's Investigations.

At the close of the committee's work Mr. McWhirter very kindly brought to the notice of the committee the results of his own investigations on the same subject. These are particularly interesting as he arrives at somewhat similar results by an entirely different method. The account of his work given below is by permission taken from a paper by Mr. H. McWhirter, which will be published in the "Journal of the Institution of Electrical Engineers."

Mr. McWhirter considers the horizontal illumination at any point P not under the axis of a symmetrical light distribution C_θ, where C_θ is the candle-power in the direction θ to the axis. The illumination at this point is $\frac{C_\theta}{h^2}\cos^3\theta$ or $\frac{C_\theta}{l^2}\sin^2\theta\cos\theta$ where h is the height of the light source and l is the distance of the point P from the intersection of the axis of the distribution with the horizontal plane through P.

This expression is zero when $h = 0$ and when $h=\infty$, i.e., when $\theta = 90°$ and when $\theta = 0°$. For a particular value of θ, found by differentiation or by plotting, this expression has a maximum value. The angle at which this occurs is called by McWhirter "the dispersive angle."

For a line of sources along a road McWhirter considers that the best height for a light source is that at which the illumination at the mid-span point is a maximum, i.e., $x/h=\tan\theta$, where $2x$ is the distance apart of the sources, but $x/h=\frac{1}{2}s$ where s is the spacing-height ratio, so that for a line of light sources the best value of s is given by

$$s = 2\tan\theta.$$

For a system of light sources arranged in a square formation the condition that the illumination at the centre of the system of four light sources is a maximum gives $x/h=s=\sqrt{2}\tan\theta$

where x is the distance apart of the sources.

This formula for the spacing-height ratio gives no information as to the uniformity ratio of the resultant illumination. If the formula is compared with those derived earlier on for uniformity ratios of 70 per cent. and 50 per cent. we have

$$s = \sqrt{2F} \text{ or } \sqrt{3F}$$
$$s = \sqrt{2}\tan\theta$$

If the last formula agrees with the first or second we should have

$$F=\tan^2\theta \text{ or } F=2/3\tan^2\theta$$

To investigate this, the distributions shown in Fig. 4 were considered, and the respective frame ratios were plotted against the corresponding values of $\tan^2\theta$ found by differentiation or plotting, and the

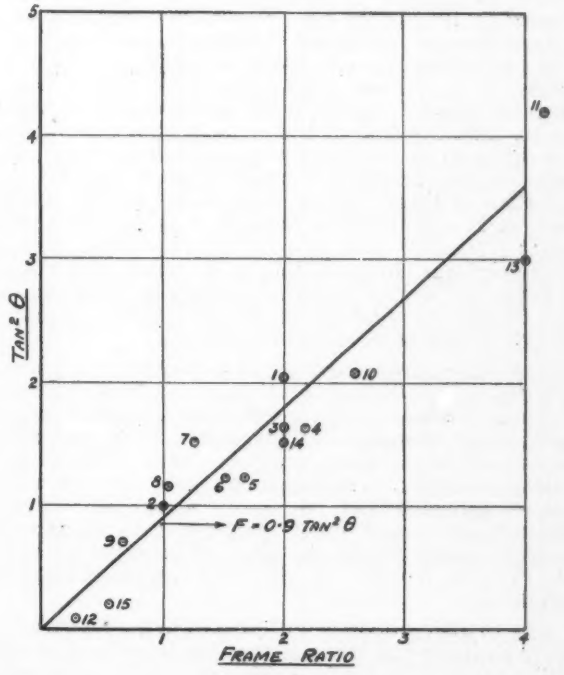

Fig. 13.

curve in Fig. 13 was obtained. It appears from this that, appraximately,

$$F = 0.9\tan^2\theta$$

so that the uniformity ratio produced by the adoption of McWhirter's formula is intermediate between 70% and 50%, and is probably nearer 70%.

1935 Meeting of the I.C.I.

At the 1935 meeting of the International Commission on Illumination in Germany the report on the subject of classification was prepared by the Austrian National Committee (12). This report discussed the various proposals which had been put forward on former occasions by various national committees. These included the British, Belgian, Japanese, and German proposals previously mentioned in this paper. The Austrian committee also put forward for international adoption a very interesting system which was somewhat similar to the Japanese proposals. This was to the effect that the flux in the

hemisphere under consideration should be considered with regard to the percentage which was emitted in each of three zones which together formed the complete hemisphere. The three zones were such as would contain equal amounts of flux if the light source were a uniform source. In angular measure they were defined as follows: Zone I. 0°—48°, Zone II. 48°—70.5°, Zone III. 70.5°—90°.

The percentage amounts of flux in these zones were then to be rounded off to the nearest 10% and divided by 10. Thus a distribution which had 24%, 36%, and 40% of the flux in a hemisphere distributed into Zones I., II., and III., respectively, would be represented by the figures 244. It was then proposed that an equilateral triangular diagram be used in which the co-ordinates of any point could be expressed in terms of its distances from the three sides. If the distance from a corner to an opposite side be taken as 10, then the sum of the co-ordinates of any point would equal 10, and there would be a small triangular area on the diagram corresponding to every combination of three figures, such as 244 or 343, whose sum is 10. The whole triangle was divided somewhat arbitrarily into nine portions by lines limiting these portions and according to the position in which a point fell whose co-ordinates were proportional to the flux in the three zones, the corresponding distribution would be classified by a name.

The names proposed were as follows: hyperconcentrating, concentrating, semi-concentrating, uniform extensive, semi-extensive, extensive, hyperextensive, semi-hyperextensive. Apparently these proposals were not very favourably received. They certainly classify distributions, but were thought to be too complicated and not easily visualised. They did not serve any other purpose than merely to classify distributions, and gave no information as to the way in which such distributions could be best employed.

The British proposals with regard to the frame ratio were explained at the meeting, but in default of any full account of them in writing they were not given any very serious consideration. A criticism of the British proposals in the Austrian report was that although they had the advantage of great simplicity they did not give sufficient information as to the distribution of flux. This point has, however, been considered earlier in this paper. It was decided that the various proposals should be considered by the national committees by the next meeting of the Commission.

The meeting did, however, reach agreement in the definition of the terms "indirect," "semi-direct," etc. These were agreed to as defined on page 84.

Conclusion.

It thus appears that after the study of the subject over a period of eight years in which a considerable amount of work has been carried out in this country and several others, we have only arrived at an agreement as regards the terms "indirect," etc.

This is, of course, an important step and should result, if carried into practice, in more unity in the general description of light distributions. It is to be hoped that it will be followed by agreement on some method which classifies distributions on the basis of the actual distribution of the flux within a hemisphere.

The British committee feel that their proposals have considerable simplicity and merit, and their connection with spacing-height ratios should make them particularly useful to the illuminating engineer.

They have not hitherto been brought before any meeting which has had any detailed information concerning them laid before it. Before it is possible to convince foreign opinion of the merits of the proposals it is desirable that illuminating engineers in this country should have them fully available. It is with the object of explaining them to British illuminating engineers and of having the benefit of their criticism that this paper has been read.

Acknowledgments.

The work of the British committee described above represents a considerable amount of work, which has been spread over a number of years. It should not be regarded as solely the work of the writer, but rather that of practically all the members of the sub-committee of which he has had the honour and pleasure of being chairman since it was set up in 1928. Written contributions, in addition to oral contributions at actual meetings, have been made by most of the members. The membership of the sub-committee has changed considerably since it was first set up. It has included, however, the following gentlemen: Messrs. Campbell, Cresswell, Good, Goodchild, Dr. English, Messrs. FitzGibbon, H. T. Harrison, Jolley, Lingard, Long, Ritchie, Stroud, Dr. Walsh and Messrs. H. C. Wheat, G. H. Wilson. Acknowledgments are also due to Messrs. Brookes and Hale, of the National Physical Laboratory, who carried out a great deal of computation work for the writer, and to Miss A. Wiggins who, as secretary of the committee, has at all times very materially assisted the committee in its work.

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DISCUSSION

Dr. J. W. T. WALSH, in opening the discussion on Mr. Buckley's paper, said he had to confess that at the introduction of the frame ratio idea he was a most profound sceptic and, indeed, a most outspoken critic and opponent. At the moment he was, perhaps, only 60 per cent. converted. At first sight the frame ratio appeared a somewhat artificial way of describing the way in which the flux was distributed from a fitting, and it was only by slow degrees that the opponents of it could be converted and feel there might be something in it. That, perhaps, also explained the very slow progress which had been made internationally. He did not believe their foreign friends were in the least bit converted to the frame ratio. No doubt they said they could not see why the British Committee had ever been foolish enough to allow themselves to be inveigled into introducing it into a specification, and a good deal of spade work would have to be done to secure its adoption internationally. However, one of the big factors which had influenced him in his half conversion was the alternatives which had been put forward by their foreign friends. Anyone who had listened to the discussion in Berlin would say that of all the proposals which had been put forward, the British system was at least the most simple and understandable and possessed a very great advantage over any other system which had been devised.

Whilst Mr. Buckley had been speaking, however, another doubt had assailed him. It was said that one of the big arguments in favour of the frame-ratio was that it correlated so well with the spacing-height ratio, but that was a double-edged argument because it immediately occurred to one that if the correlation was so good, why should not the spacing-height ratio figure for any chosen uniformity of illumination be used instead of the frame ratio. Perhaps Mr. Buckley would say what was the objection to that course being adopted. Personally, he believed it would appeal to the illuminating engineer very much more than the frame ratio which, as he had said, appeared at first to be very artificial.

Mr. H. MCWHIRTER, commenting on the formula which he himself had put forward—and which had been mentioned in the paper—and the formula which Mr. Buckley had devised, said it was interesting to note that whilst they had been put forward from entirely opposite angles, they achieved approximately the same results. Mr. Buckley, in developing his formula, considered a large installation, and assumed practical values for uniformity of illumination. In his own case he had considered a small installation and took into account the fact that the value of the illumination on the plane at the point where it was usually a minimum should be as high as possible. The fact that these two formulæ gave similar results should give cause for satisfaction to those who had to design lighting installations, as it implies that the same value of spacing-height ratio may be employed for both large and small installations.

Mr. G. H. WILSON said that as a member of the British Standards Committee he would prefer to listen rather than to speak, but he would like, at the same time, to emphasise what he thought was the chief difference between the various Continental suggestions and the British suggestion for the classification of light distribution. On the Continent they seemed to be working on light flux, that quantity which so many in this country found intangible and difficult to think about, and they tried to classify distribution according to the way in which the light flux was distributed, and certain of the methods, at all events, had on that account borne some relation to the coefficient of utilisation. The British Committee, on the other hand, had gone on the principle of trying to portray the polar curve of the lighting unit, and he, for one, found it much easier to visualise the performance of a unit from the polar curve than if somebody told him that the flux was distributed in certain percentages in certain angular zones. As he did not think it would ever be possible to get a very precise classification from any of these systems there seemed a great deal to recommend the method which endeavoured to portray that very understandable thing—although sometimes misleading—the polar curve. It would assist the Committee very considerably if the meeting could give some guidance by expressing views on the relative merits of the two systems.

Mr. C. A. MORTON agreed with Mr. Wilson that the polar curve was more satisfactory, and speaking with regard to the general problem said that he personally had the impression when the original specification was drawn up that although it was on a fundamental basis it was somewhat academic in character. It was interesting to know now that it was now possible to correlate the frame ratio with the much more practical spacing-height ratio, but the correlation was based on the assumption that the fittings were placed in squares. In practice, however, this was not so, and the arrangement of the fittings might be in rectangles. Although the specification had been in use for some years one never heard of manufacturers using the terms which were in the specification.

Mr. HOWARD LONG (communicated):—I am sorry that owing to a previous engagement I am prevented from attending. This is very disappointing because as a member of the committee I have been intimately connected with the work which is the subject of Mr. Buckley's Paper for some years. It is amusing to remember that I, in common with other members, were drawn into the committee work by our

criticisms of the early proposals. After thorough investigation, however, these early proposals have been found to be extremely sound and have been used as a basis on which the subsequent work has been built.

Mr. Buckley is to be congratulated on the way he has put together his complete story in the form of this Paper from the voluminous documents and extended work which has spread over many years and been handled by several committees, both British and International. If anybody should feel after reading or hearing the Paper they could improve on the proposals, I should recommend that they apply their ideas in actual practice for some time, when I think there is no doubt that the methods included in the British Standard Classification are those which are simplest and give the most information with the least possible effort in obtaining it.

Perhaps Mr. Buckley does not make it too clear and certainly does not emphasise that the major reason for his reading this Paper is in the hopes that it will result in a wide use of the classification.

Mr. H. BUCKLEY, in replying to the discussion, agreed with Dr. Walsh that the good correlation of the frame ratio with the spacing-height ratio might be an argument for the use of the spacing-height ratio as the basis of classification. On the same grounds the dispersive angle or the square of its tangent might also form the basis. The deciding feature was, however, that the frame ratio was immediately deducible from the polar curve while the spacing-height ratio and dispersive angle required considerable calculation, though Mr. McWhirter had shewn that the dispersive angle could be found experimentally. The frame ratio was the most easily derived quantity from the polar curve, and once derived it had been shewn how the spacing-height ratio and dispersive angle could be derived from it.

Mr. Long, in his letter, had stated that he joined the sub-committee as a sceptic, but had been converted. It was an interesting feature of the work of the sub-committee that several members joined the sub-committee prepared to curse the frame ratio but stayed to bless it.

Mr. Buckley agreed with Mr. Wilson that the polar curve was easier to visualise than the spacial distribution of flux. It was possibly on this account that proposals based on flux did not meet with ready acceptance apart from the main classification which used the terms direct, semi-direct, etc.

He agreed with Mr. Morton that lighting fittings were not always arranged in squares, but that was not essential to a method of classification. The fittings could be classified in a certain way, however it might be decided to use them, and it was an advantage that the frame ratio method of classification gave information on how to use them in the most usual case, although there would be other cases in which it would not apply. It certainly was true that the specification did not seem to have been used at all. Indeed, he had only seen one reference to it in print since it came out, and that was one of the reasons this matter had been brought before the Society. It was desired to get some discussion of it and to present information about it, for at present, outside the files of the Committee, there was no information available. It was hoped that the new specification, in view of the justification for it, which he had attempted to give, would receive attention from the users and would come into general use.

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